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Ph.D THESIS

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EVALUATION OF REAL TIME SCHEDULING POLICIES USING SIMULATION

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ABSTRACT

The purpose of this research is to investigate the effects of different scheduling operating policies in real time scheduling. The scheduling policies include due date assignment method, priority rules, process batch method and operator reassignment policy. A specific case of production scheduling in a hypothetical assembled product manufacturing system was investigated in this research.

The simulated production system encompasses fifteen work centres, each containing one to three identical machines and each machine requires one operator with all operations being perfectly efficient on all machine types. The production system produces finished products as well as components and sub-assemblies. Orders from outside the system arrive for service generated according to the exponential distribution. The orders coming to the system were classified into "priority" and "standard" orders. Processing times at each work centre are statistically independent and uniformly distributed.

A computer simulation technique was chosen as the approach method. A computer simulation written in DBASE III PLUS was used to generate the data for analysis. In order to analyse the behaviour of the simulated production system with respect to the different performance criteria, a number of performance measures were selected. These are, mean tardiness, percent tardy, mean work in progress, mean machine utilisation, and mean operator utilisation.

The 2 x 6 x 2 x 2 complete factorial is analysed by the analysis of variance (ANOVA) procedure to statistically determine whether due date assignment method, priority rules, process batch method, and operator reassignment policy or their interaction significantly affect the

performance criteria considered. Further analysis to identify where significant differences in performance occur is conducted via Duncan multiple comparison test.

Based upon the statistical analysis it was found that the relative impact of due date assignment method, priority rule, process batch method, and operator reassignment policy or their interaction for scheduling policies in real time scheduling to be dependent upon the measure of performance considered. In respect of root mean square of tardiness, the scheduling policies involving the slack time remaining (STR) priority rule are the most important of scheduling policies in minimising the tardiness of customer orders produced by the company. In respect to minimising the work in progress, there is no dominant level of due date assignment method, or priority rule or process batch method or operator reassignment policy. However, the scheduling policies involving the variable process batch (VPB) method produce the best result.

The scheduling policies involving the variable process batch (VPB) method are the best performers in maximising the utilisation of machine and operator.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

I.1 Background

Scheduling is the final step in production planning whereby all the production activities are coordinated against a time scale. It is concerned with the sequencing of a number of jobs through a predetermined set of resources while maintaining the routing of operations required for the manufacture of each individual job. The job scheduling problem is considered to be one of the most interesting problems in production analysis. During the last two decades it has received considerable attention of researchers. According to Elsayed and Boucher (1) the problem is quite complex and far from being completely solved. Several techniques have been developed for solving the problem. Some depend on highly sophisticated mathematical procedures; others use different logic procedures. The mathematical approach to the problem attempts to give an optimum solution for job scheduling and may give acceptable solutions when products pass through only a small number of manufacturing stages. However, for solving the problem with a large number of manufacturing stages (the large size problems), the algorithmic methods are impractical because of long calculating times. Also, normally an "optimal" solution is based on one criterion, whereas in practice there are usually a number of criteria which need to be taken into account.

Gupta (2) in his survey of various scheduling models, points out that much of the scheduling research, like many other areas of operations research, suffers from an over emphasis on the rigorous mathematical development of the problem and under emphasis on the realism of the formulation of the problem. He emphasised that future research into formulation of the scheduling problem should be inspired by real life problems rather than the problems encountered in mathematical abstractions.

Recently, interest has increased toward formulating the real world situation of the scheduling problem. Abdallah (13) describes how the simulation method has emerged as a logic procedure which lends itself to computer programming. By the simulation method, the reality of scheduling problems can be formulated without suffering from the need to adhere to the constraints of strict mathematical forms.

According to Galgut (4), conventional scheduling systems attempt to produce a sequence of jobs to be worked on each work centre for a week or even longer ahead but because of uncertainty in the many production factors involved, these schedules do not retain their validity for long. In order to improve the effectiveness of scheduling, it is sometimes possible to schedule jobs over shorter periods than one week, providing less opportunity for imprecision in basic data to exert a significant effect on operation. In real time scheduling, the scheduling period is reduced to the absolute minimum by scheduling each job only at the time an operator and/or a machine becomes available for the job.

Research into real time scheduling was firstly carried out by Galgut (4) at Cranfield Institute of Technology (CIT). For determining the priorities in the formulation of the problem in this research, he only used the critical ratio rule. Later, a number of other researches into real time scheduling have been carried out by several students at CIT. Amongst these researchers are Jarvis (5) and Tamkin (6) who in their work also used only the critical ratio for determining the priorities of each job to be scheduled, but they suggested the need to investigate the effects of different scheduling priority rules in real time scheduling. Based on the above factors discussed, the author has carried out research into real time scheduling which takes account of the effect of different schedule operating policies and the development of a simulation model which can be used to investigate the effectiveness of different operating policies.

I.2 Purposes and Objectives of the Research

The purpose of this research is to investigate the effects of different schedule operating policies in real time scheduling using a simulation model. A specific case of production scheduling in a hypothetical assembled product manufacturing system will be used in this research. In carrying out this research, the following objectives were planned to be achieved:

I.2.1 Investigate the effect of different schedule operating policies on various performance criteria and the effectiveness of the policies in respect to satisfying the criteria.

I.2.2 To find a system adaptable to some of the more common complexities of real job shops, such as multiple channel service centres and multiple component orders (i.e., orders involving assembly operations).

I.2.3 Formulation of a computer program for the simulation of real time scheduling.

I.2.4 To compare the developed schedule with the existing model, which uses the critical ratio method.

I.3 Scope of the Research

Certain conditions are assumed in respect of the scheduling procedure. The assumptions under which scheduling problems are generally approached are:

1. All jobs are known and are ready at the beginning of the scheduling period (the static scheduling problem).

2. All required machines, labour, materials, tools, drawings, and other necessities will be available when required during the scheduling period.

3. No machine may process more than one operation at a time.

4. Each operation on a job lot must be completed before any operation following it can begin. In other words, job lot splitting is not allowed.

5. No order cancellations.

6. The processing time for each operation is known and fixed.

7. The technological order (routing) of each job is known and fixed.

8. Set-up time, transportation time and inspection time are included in the processing time.

9. The due dates of jobs are known and fixed.

10. There is only one machine of each type in the shop (there are no groups of similar machines).

11. In process inventory is allowed.

12. The routing of operation required for manufacture of the job is fixed. Thus, alternate routing (alternate work centre) is not considered.

13. No job lot may be processed by more than one machine at a time or lap-phasing is not permitted.

14. No over time or sub-contracting is permitted.

15. No allowance is made for scrap or rework.

In order to achieve more realistic results in building the model during the research, some of these assumptions have been relaxed. Assumptions relaxed are assumptions 1, 2, 4, 6, 7, 8, 9, 10, 12.

I.4 Some Definitions

"Sequencing" is concerned only with the ordering of operations on a single machine, while "scheduling" is simultaneous and synchronised sequencing on several machines. However, it is found that no greater clarity resulted from both the above definitions, and the two terms are used essentially as synonyms in many writings. Panwalker and Iskander (7) reported that in the sequencing/scheduling literature terms such as "scheduling rule", "dispatching rule", "priority rule", or "heuristic" are often used synonymously. Gere (8) has made an attempt to distinguish between priority rules, heuristics, and scheduling rules. He considers priority rules as simply a technique by which a number (or value) is assigned to each waiting job according to some method and the job with minimum value is selected. Further, Gere defines a heuristic to be simply some "rule of thumb", whereas a scheduling rule can consist of a combination of one or more priority rules and/or one or more heuristics. The term "priority rule" that is defined by Gere (8) is used in the following chapters of this Thesis.

In respect of the job-shop scheduling problem, a job-shop is defined as consisting of a set of machines and manpower. Subsets of identical machines are called "machine groups" or "work centres". A job-shop produces products as output from raw materials and bought out items as input. A product has associated with it a routing (a technological order) which is a set of ordered operations to be performed at work centres. The ordering restrictions or precedence relationship within the routing require the completion of one or more operations before another may be started.

A product consists physically of one or more parts. If a product consists of only one part and the sequence of operations upon it is uniquely specified, this is called a "serial product". On the other hand, if a product consists of two or more parts which must ultimately be assembled before the product is completed and the sequence of operations on each part is uniquely specified, this is called a "serial-parallel product".

Each order for a product is assigned an arrival date and a due date. The arrival date, or release date, is the date or time at which an order is released to the shop. It is significant as being the earliest time that processing of the first operation of the job (order) could begin. Meanwhile, the due date is the time at which the customer would like to have the job delivered to his premises or the date which is negotiated between the customer and producer (company). This due date is a point in time after which completion of an order is considered tardy and before which completion is considered early.

Since operations take finite processing times and the number of machines and manpower is limited, there exist queues of jobs waiting for the next process, although the number of jobs in a queue may be zero. For multiple parts orders there exists an additional delaying state which occurs when parts are ineligible for processing because other parts have not completed their operations which precede the assembly operation. The state of the waiting parts is called the "assembly delay time". The total elapsed time from release of an order to its completion is called the "flow time".

I.5 Thesis Organisation

This report embraces the problem areas of an industrial scheduling problem encountered in a certain type of manufacturing system and is organised so as to fulfill the purpose and objectives laid down in section I.2.

In Chapter I is explained the background of the research, assumptions which are made during the development of the model and some definitions or terminology that are used in this report. Chapter II describes the review of available literature associated with the industrial scheduling problem and the different approaches proposed to solve the problem.

Chapter III explains the real time scheduling system, the concepts that are used to develop the real time scheduling, the relationship between simulation and real time scheduling system, the problems of real time scheduling, and the logic procedure by which the real time scheduling works.

Chapter IV presents the methodology used in this research, such as the shop size of the production system simulated, arrival rate and order size distribution, method of determination of delivery date, etc.

Chapter V is concerned with the real time scheduling simulation system design, where the specification and procedures of the developed system are described, such as the flow chart, the program and sub programs, and information files which have been established in order to make the system work.

Chapter VI deals with the analysis of variance (ANOVA) procedure applied in the analysis of output of simulation runs.

Chapter VII presents and analyses the results of the simulation runs using the ANOVA procedure to determine statistically whether the due date assignment method, priority rule, process batch method and operator policy or their interactions significantly affect the performance of the job shop considered in this research.

Chapter VIII includes a summary of the findings and suggestions concerning potential applications of the system developed to real situations. Directions for further research are also indicated.

CHAPTER II

LITERATURE REVIEW

II.1 Introduction

According to Graves (9), scheduling is implemented not in isolation, but as part of a total operating system. For instance, scheduling decisions affect and are affected by capacity planning decisions, material requirement planning decisions, various marketing decisions, such as product promotion, and transportation/distribution schedules.

Carrol (10) has described scheduling as the process of determining which of several eligible jobs should be performed next at a free work centre. If there is a job to be manufactured on 'm' machines according to specific technological requirements (routings), such that it has to be processed on each machine by a specific procedure, then this specific procedure is called "technological order" by Abdallah(3).

It can be represented by a vector Vm where 'm' is the number of the machine required to process a certain operation of the job. If there are 'n' jobs to be processed on 'm' machines, then the technological order can be represented by an n x m matrix which is called the "technological order matrix".

Unfortunately, the number of alternative sequences possible for any practical situations becomes so large with increasing values of 'n' that examination of each individual alternative becomes practically impossible, even with the use of the most advanced computers. As the formulation of a mathematical model to cater for an n x m model has not been possible, the researchers and management experts have been recommending the use of certain predetermined priority rules for the scheduling function. Most of the research, during the last two decades, has been concentrated on the evaluation of different priority rules by simulation of production characteristics in various situations. These researchers have recommended the use of different priority rules for various conditions.

II.2 Classification of Scheduling Problems

Day and Hottenstein (11) have classified the scheduling problems into two categories, "static scheduling" and "dynamic scheduling" problems. Elmaghraby (12) classified the approaches in dealing with static scheduling problems, namely combinatorial approaches, general mathematical programming, reliable heuristics, and Monte Carlo sampling. For dynamic scheduling problems, Jackson's decomposition principle (11), to date, is the most powerful analytical method in the study of dynamic job shops and dynamic flow shops. Meanwhile, because of the stochastic nature of the parameters in dynamic job shops, most researchers in their studies used the simulation approach to attempt to solve the problem.

The classification of industrial scheduling problems generally depends upon the flow of the job during processing and the characteristics of the technological order (routing). Based on these characteristics, the scheduling problems can be classified into flow shop problems and job shop problems. In the flow shop scheduling problem the technological order of every job on the various machines is the same. The arrangement of the machines in this type is unidirectional and can be numbered in the same order of processing of the jobs. Job shop scheduling is characterised by diverse routing of the jobs and the technological order of each job is different. Much of the research literature in scheduling refers to the job-shop scheduling problem. According to Conway (13) the job shop scheduling problem is a fascinating challenge. Although it is easy to state and to visualise what is required, it is extremely difficult to make any progress whatever towards a solution. Further Conway stated "Many researchers have investigated the problem and the problem continues to attract researchers, who just cannot believe that a problem so simply structured can be so difficult, until they have tried it".

II.3 Some Approaches to Solving the Scheduling Problems

Several different approaches have been suggested by researchers in the attempt to better understand the scheduling problems.

The different approaches are briefly described below:

II.3.1 Combinatorial Approaches

Combinatorial Approaches rely on the changing of one permutation to another by "switching around" of jobs and the selection of the active schedule which give an optimum or near optimum solution that satisfy a given criterion. A series of literature references for combinatorial approaches have been published, such as Gapp (14), Gilmore (15), Jackson (16), Johnson (17), McNaughton (18) and Mitten (19). A further modification to this approach by some researchers has resulted in a reduction of the computational efforts, but the range of its applicability for the large size problem is still limited.

II.3.2 General Mathematical Programming

General mathematical programming approaches to scheduling problems include linear, dynamic, convex, and quadratic programming, integer programming, networks of flow, Lagrangian methods and the like (12). There are a great many articles published on this subject, some of them being Balinski (20), Bowman (21), Danzig (22), Manne (23), and Wagner (24).

The integer programming approach states the problem of scheduling in the form of a set of linear equality constraints and a linear objective function. The constraints depend upon the structure of the problem and the objective function is defined according to the criteria of optimisation. Because of the excessive computation required, for numerical solution of the scheduling problem using this approach, successful application has not been achieved, even for relatively small size problems.

II.3.3 Reliable Heuristics

These approaches are also known as "combinatorial programming" or "controlled enumeration". According to Elmaghraby (12) this approach is developed on the basis of two principal concepts, the use of a controlled enumeration technique for considering all potential solutions and the elimination from explicit consideration of particular potential solutions which are known from dominance, bounding, and feasibility consideration to be unacceptable. Elmaghraby restricts the meaning of "combinatorial programming" to problem solving procedures based on these concepts which are reliable in the sense that when carried to completion, they guarantee the discovery of an acceptable solution if one exists, or the knowledge that one exists.

An alternate name for such a method is "branch and bound". The idea of a "branch" stems from the fact that in terms of a tree representation of all possible solutions to the problem the procedure attempts to select only those branches of the tree which are likely to provide satisfactory answer to elaborate and evaluate. "Bound" emphasises the effective use of means for determining the limiting value of the objective function at each node of the tree both for eliminating branches which will not lead to an effective solution and for choosing branches for further elaboration and evaluation.

Brooks and White (25) suggest an algorithm to find an optimal or near optimal solution to the scheduling problem. They suggest that in a general sense, the make-span cannot be less than the total processing time. Based on this lower bound, they suggest branching to a job which determines this lower bound, since any delay in this job has a tendency to increase the make span. Once this branch is selected, the lower bound can be modified by adding the remaining time of the jobs to the completion time and the next branch selected. This procedure, of calculating the lower bounds and branching, is continued until a complete sequence is generated. All those branches which have a lower bound less than the make-span of the completed sequence are examined and the sequence with the minimum make span is accepted as an optimal or near optimal sequence.

The branch and bound approach has been considerably modified by Greenberg (26) and Schrage (27). The modification to this approach can be used to solve the general n job, m machine scheduling problem. Even with this modifiction, this approach has not been able to solve problems of practical sizes due to the constraints made in the formulation of the problem and the excessive computation required.

II.3.4 Jackson's Decomposition Principle

In order to state the principle the following assumptions are made:

- the arrival times for each job arriving from outside the system are exponentially distributed;
- the processing times at each machine are exponentially distributed;
- the jobs are routed to a machine by a fixed probability transition matrix. This matrix defines the probabilities of a job going

from either machine "m" to any other machine in the shop or from machine "m" to the customer;

- the priority rule at each machine is "first come first served" (FCFS).

Given these assumptions, the system can be decomposed into one of a network of independent individual machine queueing systems. This result was based on the fact that under FCFS, the output of a single queue is exponential if the inter arrival and service times are exponential. In the dynamic job shop situation, the output of one machine becomes the input to the next in a network of queues.

Jackson's decomposition principle has been generalised to apply to systems on which the rate at which jobs are processed at each machine is an essentially arbitrary function of the queue length at that machine. The lengths of the individual waiting lines again turn out to be independent, with distributions identical to those for similar isolated queuing systems.

II.3.5 Simulation Technique

Emshoff and Sisson(28) have defined simulation as follows: "a simulation is a model of some situation in which the elements of the situation are represented by arithmetic and logical processes that can be executed on a computer to predict the dynamic properties of the situation". Meanwhile, Naylor (29) gives another definition for simulation as follows: "simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models, that describe the behaviour of a business, or economic system, over extended periods of real time". According to Edward (30), simulation is not new as an aid in solving problems.

Engineers have always used mechanical models of ships, aircraft, and space vehicles to simulate full-scale prototypes under actual operating conditions in test tanks and wind tunnels. However, the use of simulation as a management tool is relatively new. By using digital computers, management can simulate the behaviour of entire business and manufacturing systems in order to evaluate overall performance under the influence of interacting factors.

Simulation as a management tool consists of representing the real world in terms of a mathematical model that will react similarly to the situation after which it is patterned. A simulation model can be very general or quite specific, depending on its intended use. For example, the real world of sales, marketing, manufacturing, production control, market forecasting, and distribution of a product or line of products can be converted into a mathematical model that can be manipulated by a digital computer. The model would represent the actual situation and take into account structural interrelationships that would be affected by any proposed changes. The accuracy of the model would determine the accuracy of the results of the simulation.

As an example of the use of simulation, consider a manufacturing firm that is contemplating building a large extension onto one of its plants but is not sure whether the potential gain in productivity would justify the construction cost. It certainly would not be cost-effective to build the extension and then remove it later if it does not work out. However, a careful simulation study could shed some light on the question by simulating the operation of the plant as it currently exists and as it would be if the plant were expanded.

The simulation technique has been used to study industrial scheduling problems. The job shop problem as a special subject of scheduling problems has been particularly the subject of numerous simulation studies since the early days of computer simulation.

In a simulation study of sequencing in batch production Hollier (31) used different rules to select jobs from the machine queue. A new feature has been introduced to the structure of the simulation model by including the set-up and transit time. The set-up time variable is also used as a priority function for one of the rules. The main conclusions from the reported research of job shop scheduling simulation is that the "shortest operation time rule" is the most effective priority rule in producing the best performance when the criteria to meet is the maximisation of throughput, but it is not effective if the criteria is meeting due dates. Conway (57) studied three due date based rules, earliest due date, slack time remaining, and slack time remaining per operation. All three due date based rules produce a lower variance of job lateness than the "first come first served" or the "shortest imminent operation time rule". Conway found that the "slack time remaining per operation rule" produced a smaller variance of job lateness and a smaller number of tardy jobs than either the "slack time remaining" or the "due date" rule.

In many of the studies pertaining to research by using simulation techniques on the effectiveness of various job-shop dispatching rules, a basic assumption regarding the type of operation is generally made. A search of the literature indicates that researchers have generally assumed non-assembly operation; relaxing this assumption to include scheduling of assembly operations has not been extensively studied. Examples of studies which have investigated the assembly operation system are Carrol (10), Fryer (32), Harris (33), Nanot (34), and Goodwin (35).

Nanot, in his study, has simulated the job-shop consisting of 2, 4 or 8 machine groups each having a single machine. The job-shop simulated produces assembled products. In building the model the following assumptions have been made.

1 The arrival of jobs in the system is stochastic in nature.

2 There is a single queue for each machine centre.

3 No job is processed on more than one machine at one time.

4 Transportation time between centres is zero.

5 Subcontracting and overtime are not allowed.

6 Machine breakdowns, fabrication errors, and similar disturbances do not occur in the system.

7 Set-up time is implicitly included in the processing time for each operation.

Meanwhile, Goodwin (35) has simulated a multistage production system consisting of 28 work centres which are arranged in four major production stages. The main objective of his study is to examine the impact of the operating policy rules on multistage system performance and to determine whether the results of such research in nonassembly environments can be generalised to assembly environments. He assumed that, the order inter arrival time into the system is drawn from an exponential distribution, the order size is generated from a uniform distribution, and orders are processed separately in a lot-for-lot fashion and there is no notion of lot splitting or combining several orders into one lot. Results show that performance of the production system is significantly influenced by the operating policy rules, although the relative impact of the rules is dependent on the performance measure considered. This research indicates that not all previous research of despatching rules in nonassembly systems can be generalised to assembly systems.

From the assumptions that have been made by the previous researchers, it can be seen that several restrictive assumptions have been maintained in most inquiries because relaxation of these assumptions introduces considerable complexity into the scheduling problem.

II.4 Simulation of Dynamic Job Shops

In a job shop, a job may require several different operations provided by different machines or work centres and may have to wait in several queues. Generally the jobs arrive at the shop randomly over time; such a job shop is called a "dynamic job shop". The dynamic job shop scheduling problem has been studied extensively during the last two decades. The contribution of analytical techniques to the problem of sequencing has been very limited in complex situations involving the dynamic behaviour of the job shop and the simulation model is currently considered to be the only feasible method of approach.

Day and Hottenstein (11) discussed the simulation of dynamic job shops and presented an extensive list of references as shown in Appendix A Page 159. Most researchers in the simulation studies have used the following information:

- arrival pattern, processing time and set up time distribution

- number of machines, type of shop, due date of finished products

- performance criteria used

- type of investigation.

However, they never take into account the availability distribution of materials, operators and some other requirements before a job can be scheduled or loaded on a machine.

CHAPTER III

REAL TIME SCHEDULING

III.1 Introduction

Real time scheduling is a recent approach to solving the scheduling problem. This approach was first developed by P. E. Galgut at the Cranfield Institute of Technology (CIT) in 1981 and implemented in a batch shop environment. There were some students in CIT who have also used this method for their research.

The concept of real time scheduling (RTS) is very simple and avoids the problem mentioned regarding schedule imprecision. Sequenced lists of jobs are not produced, instead manufacturing instructions are issued one job at a time.

According to Galgut (4), in RTS jobs which can be scheduled are only those which can be immediately worked on because they have been completely kitted up, tools and drawings are available, and all other necessary requirements have been accomplished (4). The RTS will identify all of the jobs available to start on a free work centre.

III.2 RTS Concept

A production planning and control system of a job shop must satisfy objectives determined by management. Generally there are four main objectives for a typical system.

1 Minimise the time required from receipt of order to the start of a job at the first manufacturing operation. Process and operations planning,

tooling, raw materials, and other requirements must be provided with minimum delay and maximum flexibility.

2 Deliver orders on time to customers.

3 Effectively utilise men, machine, material and time resources.

4 Provide shop management with the information needed to improve and maintain a timely, orderly and continous flow of production material through the shop.

Regarding these four general objectives, the scheduling as a part of production planning should consider all the following functions:

1 <u>Receive and Audit New Orders.</u>

In general, the job shop receives its authorisation to initiate work from either a customer's purchase order or from an in-company shop order. Each order has a quantity, due date, and engineering specification. Each of these order characteristics must be reviewed for validity and reasonableness.

2 <u>Establish Manufacturing Processes and Operations Planning.</u>

Such information as raw material, size and amount, operation sequence, work centre routing, operation method instructions, and operation time standards must be generated for each order. Once this information is generated, it can be stored in a master file to be used for any repeat orders for the same design.

3 Determine the Loading for Each Order

The statement of the available capacity of man-machine resources in the shop and the loading parameters for various work centres are the necessary information for this function. Based on the characteristics of an order, the process and operations planning for the order, and the capacity and loading parameters of the shop, the loading file for the order can be determined. The loading file should consist of the capacity which is needed and the start date when every operation should be performed.

4 Scheduling Program for Each Work Centre in the Shop

This function should be performed in real-time in order to reduce the effect of the imprecision in the basic data. The objective is to give the sequence by which work is to be processed at each work centre in the shop during the scheduling period. Any method used to make the sequencing decision must take into account such variables as the capacity of the work centre/machine, job lots currently waiting to be processed at the given work centre, the work in process being routed to work centre during the scheduling period, the relative priorities of all the jobs to be processed at the work centre, and the material flow and other requirements in the shop. Also, work must be scheduled to work centres consisting of a group of common machines so as to balance the load amongst all the machines.

It is obvious that any method depends on an accurate, responsive shop floor feedback system to pinpoint the location of each job lot before the sequencing decisions are made.

5. Maintain Shop Floor Feedback for Production Status Update

As each job lot progresses through its manufacturing cycle activities such as completion time of a certain activity, rejection of parts, breakdown of machines, etc. must be collected and communicated to the system. In this way the control system can account for the exact whereabouts and remaining processing operations for each job lot in the shop and the status of the machines in each work centre.

6. Allow for Revision

Provision must be made in the system for revising the original parameters of jobs which have been loaded to each work centre. As changes are made to the parameters, the system should be capable of recalculating the schedule dates for the order in order to obtain the estimated capacity available or other resources in a certain time. The system must be programmed so that any changes can be made either by the foreman or by the people who operate with the computer.

III.3 Simulation and Real-time Scheduling

Since the computer is capable of compressing the time of the occurrences of future events into short intervals of present time, interacting factors can be tested in numerous ways to provide management with many variations of business situations. By using a computer, simulation can be a powerful tool in the managerial decision process since it can provide a method for testing and evaluating corporate plans long before management must commit itself to action.

Martin (36) defined a real-time computer system as one which controls an environment by receiving data, processing data, and taking action or returning results sufficiently quickly to affect the functionning of the environment at that time. "Real-time" is a term that is defined differently by different authorities. The question of "response time" may enter into the definition. Response time is the time the system takes to react to a given input. In using a computer to control a set of operations a short response time is usually necessary. The speed of response differs from one type of system to another according to the needs. In a system for radar scanning a response time of milliseconds is needed. (A warehousing control system may have a response time of thirty seconds.) For scheduling a response time of ten to fifteen seconds may be needed. The implications of a real time system and simulation technique for scheduling problem research is in no doubt. It is assumed that the scheduling process is an attempt to solve the global problems of sequencing, that is, an attempt to also consider information that exists beyond the limits of the individual workcentre. But the scheduling process is constrained by imprecision of information. By this is meant that information on events which occur between formulation of the plan and the time of execution is imprecise. Suppose an optimal schedule is issued; the optimal schedule is likely to be no longer feasible. According to Galgut (4) when it comes to practice, many difficulties arise, such as materials not arriving on time, operators being absent and machine breakdowns, so it is found to be increasingly difficult to operate in accordance with the proposed schedule.

From the description above can be drawn the conclusion that the simulation can be a powerful tool in order to study the performance of real time scheduling system under some projected set of operating conditions.

III.4 Real Time Scheduling and its Problems

The job sequencing problem is to schedule a set of "n" jobs on "m" machines so that the result is optimal with respect to a given measure of performance. Early studies employed models that were highly restricted by simplifying assumptions such as; no job cancellation, no machine breakdown, no assembly operation, and materials, drawings, tools and other requirements are always available, etc. These models also attempt to organise a sequence of jobs to be worked in each work centre over a period of time, usually a week but often longer.

Galgut (4) has described that the shorter the scheduling period, the less severe will be the effects of imprecision on schedule efficiencies. In real time scheduling the scheduling period is reduced to the absolute minimum by scheduling each job only at the time that all the requirements to manufacture the job become available. Therefore, if there are jobs to be scheduled, each job is scheduled at the latest possible time which will prevent idle time at the resource.

A number of researches into real time scheduling have been carried out as described previously. Research in this real time scheduling has some problems as follows:

1. The loading of orders coming to the job shop was not carried out in a systematic way.

2. For determining the priority of each job to be scheduled only the critical ratio method has been used.

3. Most of the researchers have tended to concentrate on sequencing simple, single component jobs that required no coordination of multiple parts for assembly work. Except Galgut (4), the area of research has been in a job shop assembly system.

III.5 The Logic Procedure of Real Time Scheduling

In real time scheduling, the scheduling of a job on a certain machine occurs only when the required manufacturing facility becomes available. At this point in time all the jobs waiting for this facility are examined and those where all the necessities for production (i.e. materials, operator, tools and drawings) are available are prioritised, all other jobs being disregarded. According to the priority rules used, the most urgent job is identified and manufacturing instructions are issued for it. The flow diagram shown in Fig. III.1 describes the basic cycle of the real time scheduling process, it being repeated every time an operation is completed.

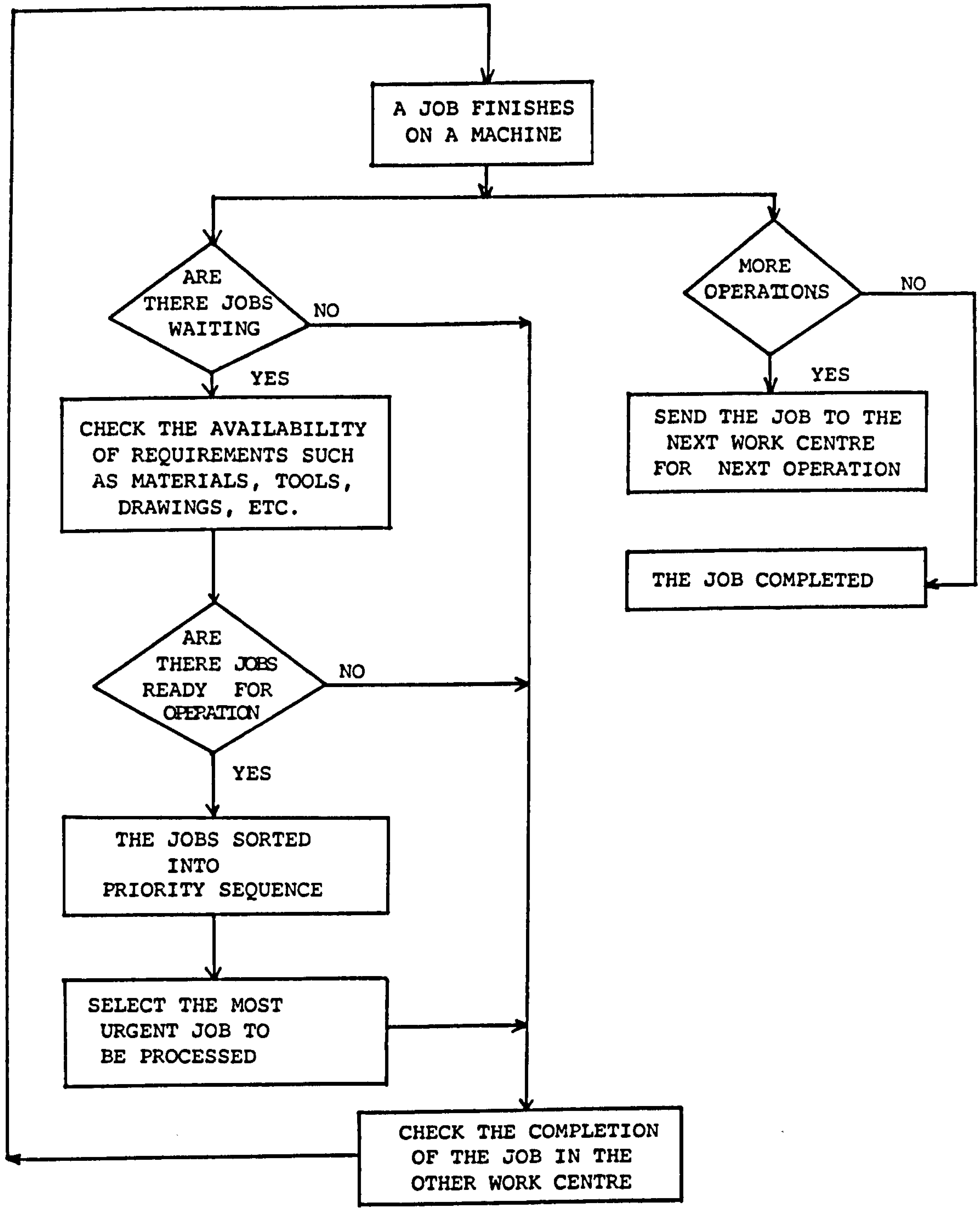


FIG. III.1 The Diagram of the Basic Cycle of the Real Time Scheduling Process

CHAPTER IV

RESEARCH METHODOLOGY

Since no promising analytical techniques exist for analysis of a dynamic job shop, computer simulation was chosen as the approach method during the research. This chapter discusses factors that influence the performance of operating policies within simulation, including shop size, product structure, arrival rate and order size distribution, method of determination of delivery date and performance criteria used.

IV.1 The size of the simulated production system.

Baker and Dzielinski (37) have tested dispatching rules in shops of various size and found that the size of the shop does not affect the relative performance of the rules. This finding is convenient in that it is cheaper to simulate a small shop.

Buffa (38) concludes that "since shop size has never appeared as a major variable, it seems that we may be able to experiment with relatively small shops and generalise the resulting conclusions". In association with this finding and to facilitate this research, a computer simulation model of a hypothetical assembly-production system that mainly produces various types of mixers (39) was used to generate data during the scheduling period. The system simulated is the dynamic production system. The word "dynamic" simply means that orders from customers arrive randomly into the system throughout the period of study.

The production system encompasses fifteen work centres, each containing one to three identical machines and each machine requires one operator with all operators being perfectly efficient on all machine types. The characteristics of the system are presented in Table IV.1.

IV.2 Product Structure.

The production system produces two major types of mixers, namely side mixer and top mixer. Besides producing finished products (mixers), the system also produces components, spare parts and sub-assemblies. Moreover, the products produced may differ in terms of size, materials, number of impellers, and number of blades per impeller. The specification of each product produced is enclosed in Appendix B.

Each product is defined by a set of operations that is required to produce it. The products have initial operations ranging from one to seven. After the initial operations of a product are completed, the product's components proceed through the system to the next highest stage along the fixed routing. This process is repeated at each stage of the production system until the product is completed. Figure B.1 in Appendix B (page 170) depicts the product structure of a top mixer with its routing requirements.

Table IV.1 The Characteristics of the System Simulated

W/C No.	W/C Name	W/C Code	No.of Units	Capacity hrs/wk	Eff. (%)	Std.Cap. hrs/wk
401	Despatching	DESP	1	40	90	36
402	Inspection	INSP	2	80	90	72
403	Assembling	ASS	2	80	90	72
404	Stores	STR	1	40	90	36
405	Radial Drill	RADR	2	80	90	72
406	Saw	SAW	3	120	90	108
407	Welding	WELD	2	80	90	72
408	Pillar Drill	PIDR	2	80	90	72
409	Miller	MILL	3	120	90	108
410	Lathe	LATH	3	120	90	108
411	Multispindle Drill	MSDR	1	40	90	36
412	Hand Grinder	HGRN	1	40	90	36
413	Ramp Press	RMPS	1	40	90	36
414	Rotary Grinder	RTGR	2	80	90	72
415	Grinder	GRND	1	40	90	36

IV.3 Arrival rate and order size distribution.

In many studies concerning research on the effectiveness of various job shop dispatching rules, a basic assumption regarding the distribution of arrival rates for incoming orders is generally made. Day and Hottenstein (11) reported that many articles indicate that researchers select arrival rates from a Poisson distribution or assume interarrival times to be exponentially distributed. Reinitz (40), Jackson (41) and Nanot (34) employ the Poisson distribution in their studies. Conway (42), Nelson (43), Hottenstein (44) and Jackson (45) have indicated the use of exponentially interarrival times in addressing their specific problems. Elvers (46) studied the effect that various arrival rate distributions have on the relative success of job shop dispatching rates. He concluded that the distribution with respect to shape and range of the arrival rate for incoming orders is not a significant variable in evaluating the relative effectiveness of dispatching rules.

Based upon this finding, the order interarrival time for this research is drawn from an exponential distribution whose mean is 10 hours (1.25 days) and the minimum interarrival time is 4 hours (0.5 days). Meanwhile the order sizes for each product are generated from a uniform distribution of integer values greater than or equal to the minimum order size and less than or equal to the maximum order size for each product, as presented in Table IV.2.

Thereafter, random numbers are generated to determine the size, material, number of impellers, and number of blades per impeller of each incoming order with the assumption that each product has an equal probability of arrival in terms of these characteristics.

Table IV.2 The minimum and maximum order size of each product

PRODUCT TYPE	ORDER SIZE (UNITS) MINIMUM	MAXIMUM
1. Top mixer size 1	25	30
2. Top mixer size 2	25	30
3. Top mixer size 3	25	30
4. Side mixer size 1	20	25
5. Side mixer size 2	20	25
6. Side mixer size 3	20	25
7. Sub assembly	25	30
8. Top mixer cage	12	16
9. Side mixer cage	16	20
10. Impeller	25	35
11. Bearing cover	30	40
12. Coupling	20	25

IV.4 Lot sizing.

Optimised Production Technology (OPT) is a finite capacity scheduling and simulation system that has applicability to a variety of discrete manufacturing and flow process operations. OPT suggests (1) that batch sizes are not fixed for all operations but comprise two components.

- A "transfer" batch which is that quantity without which an operation will not be activated. This quantity is a function of managerial parameters that are plant and process specific and defines the basic "units of work" that are appropriate to a particular manufacturing environment.

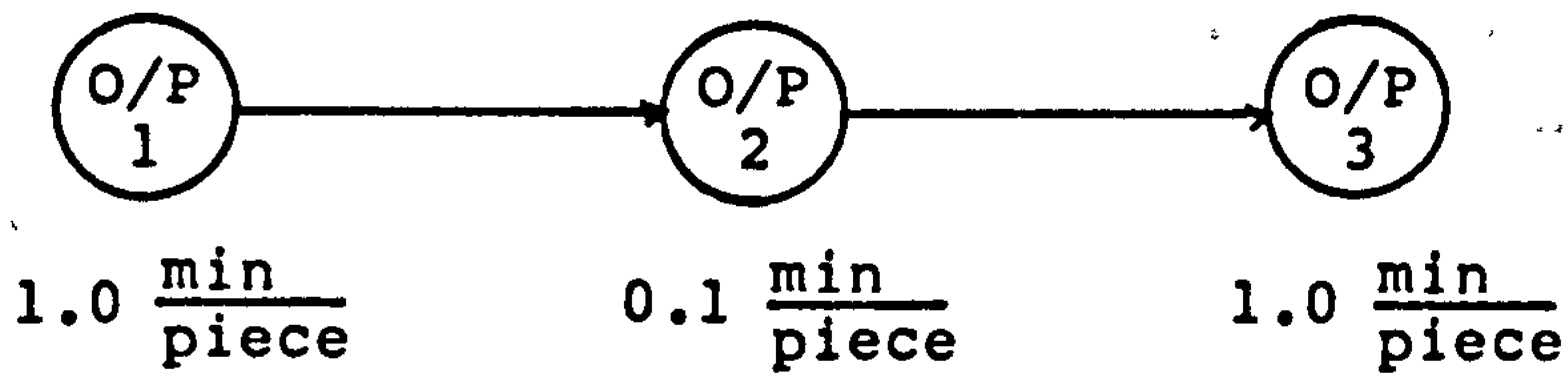
- A "process" batch that is dynamically set at each job step and which is an integral multiple of the transfer batch. The process batch is established dynamically for each operation and balances inventory cost, set-up costs, component flow requirements and the needs for managerial control and flexibility.

According to Fox (66), the OPT system employs this batch size method in order to generate overlapping schedules that significantly reduce lead times. Meanwhile, the traditional Material Requirement Planning (MRP) system employs the fixed batch size method for the scheduling process.

Fig. IV.1 contrasts how a traditional MRP system and OPT system handle the same scheduling problem. The MRP system employs only a fixed process batch of 1000 units and takes 2100 minutes to process it through the three operations. Meanwhile the OPT system employs

Product X, lot size = 1000 pieces

<u>Process</u>



Traditional MRP	OPT
Approach Uses single fixed process batch of 1000 pieces at each operation.	**Approach** Uses two batch size - Transfer batch = 100 - Process batch is variable.
Schedule	**Schedule**
O/P Process batch	O/P Process batch Transfer batch
1 1000 1000 min.	1 1000 100 1000 min.
2 1000 100 min.	2 300,300 200,200 100 100 min. 30 30 20 20
3 1000 1000 min	3 1000 100 1000 min
Total lead time 2100 min.	Total lead time 1310 min.

Fig. IV.1 Comparison between traditional MRP and OPT in schedule approach two types of lot sizes - a fixed transfer batch and a variable process batch. The total lead time to process 1000 pieces through this scheduling approach is only 1310 minutes. This example shows that the OPT system enables a 38% reduction in lead time to be achieved compared with the MRP system in respect of the scheduling process.

However, the case given only considers one order at the given period time. In reality, there are likely to be several orders competing for the same facility in order to meet their delivery dates. Therefore, it is necessary to investigate the effect of each approach on the performance of the job shop scheduling process. In relation to this, the two approaches discussed previously would be included as one of the elements of operating policies considered during the research. The batch size method of an MRP system in this research is termed "fixed process batch" (FPB), while the batch size method of OPT as "variable process batch" (VPB).

Furthermore, orders are processed separately in a lot-for-lot fashion, and there is no notion of combining several orders into one lot. In other words the maximum process batch size is equal to the order size. Determining the optimum sizes of transfer batch and process batch is beyond the scope of this research. These sizes will arbitrarily be determined and based on the order size.

IV.5 Method of determination of delivery date.

The ability of a production system to meet delivery dates or dates of desired completion is an important performance criterion. Completion of orders ahead of due dates or delivery dates would result in storage costs if the orders could not be shipped ahead of schedule. On the other hand, if orders (jobs) are completed later that the due dates, customer dissatisfaction may result. Also, if any penalty clauses are included in the contract, they may be invoked by the customer. Therefore, as orders are generated it is necessary to assign a realistic delivery date to each arriving order.

Conway (42) defines two types of due date assignment procedures to arriving orders.

1. Exogenous due date assignment.

   The salesman or customer determines the due date which is usually random in nature and subject to negotiation before acceptance by the manufacturer. This procedure consists of:

   - Constant (CON); the salesman stipulates a due date at a uniform number of periods into the future,

   - Random (RAN); the customer establishes the due date.

2. Endogenous due date assignment.

   The manufacturer establishes the due date which is determined by an estimate of the expected throughput time for the accepted order. This procedure is based on either:

- total work content (TWC)

or the number of operations (NOP).

Conway found that the performance of all orders relative to mean lateness and number of tardy jobs was somewhat sensitive to the method of due date establishment. However, most researchers agree that the TWC method is the most rational method of assigning due dates. With the TWC method, the due date of the finished products can be calculated as the time of arrival plus a constant times the total processing time.

Elvers (47) has investigated the performance of 10 dispatching rules over five variations of the TWC due date assignments method (by setting the due dates as 3, 4, 5, 6, and 7 times the total job processing time). He evaluated the rules using a tardiness criterion. His findings showed clearly that when a due date is set at six times the total processing times, the shortest imminent operation time rule performed best. Similar rules, such as the shortest remaining processing time, also performed well.

In recent years, with the advent of Material Requirement Planning (MRP) systems, another method of assigning due dates has come into practice (48). Using the bill of materials and data on queues at each work centre, transit times involved, mean set-up and run times, one can develop a critical path-type diagram of the product manufacturing sequence and use this to establish manufacturing lead times.

Based on these findings, two methods of due date assignment are tested during the research, namely TWC method and MRP method. Since the system produces the assembled product, the longest path is used to measure the total processing time for the TWC method. The mathematical model of the TWC method and an example of determining the due date of a finished product by using this method is shown in Appendix B (page 172).

IV.6 Priority Rules Used.

This is the main decision variable under investigation. According to Rowe (49), although many priority rules have been proposed in the literature, no analytical formulation has been made which assures optimality. However, priority rules can do more than accelerate one or more jobs through the shop at the expense of other jobs. Conway (50) pointed out that they can improve the average throughput time of all the jobs. Hence, though optimality will be difficult to achieve, it has been demonstrated that the choice of priority rule can affect aggregate measures of shop performance.

A priority, or "dispatching" rule is used to select the next job to be processed from a set of jobs competing for the same facilities. The priority rule selected can be very simple or extremely complex. An example of a simple priority rule is to select a job at random. A complex rule might be one that selects the job with the shortest due date whose customer's inventory is less than a specific amount.

Blackstone (48) pointed out that there are thirty-four dispatching rules which can be used in industrial practice. Considering these facts, this research used the commonly selected priority rules employed in industrial scheduling problems; following is a description of these rules:

1. First come first served (FCFS).
   This is the simplest and most commonly used dispatching rule. This rule follows the manner in which customers queue for service at a supermarket checkout. The first arrival job in the queue of the machine receives the highest priority to be scheduled. In a practical sense, FCFS is an attractive choice due to its simplicity of definition and usage.

2. Shortest imminent operation time (SIOT).
   When several jobs compete for service at a facility, the job whose processing time on that machine (facility) is the smallest gets priority. For a simple queuing system (one machine with exponentially distributed interarrival and servicing time), Conway and Maxwell (51) have found this rule to be optimal in terms of mean waiting time. For a network of queues, Conway pointed out that this rule is optimal in terms of mean idle time.

3. Earliest due date (EDD).
   The principle advantage of due-date-based rules over processing-time-based rules is a smaller variance of job lateness, and often a smaller number of tardy jobs. Conway (42) has shown that this advantage is especially manifest when due dates are established as some multiple of total processing time. This rule gives the highest

priority to the job with the earliest due date for the finished product.

4. Slack time remaining (STR).
Slack time is usually thought of as the amount of time left before some deadline. The slack for each job can be defined in either of two ways. In the first case, "static slack" is defined as the time remaining to the due date of the finished product. Upon arriving at the first work centre, prior to joining the queue, a job's slack is determined as the difference between its due date and its time of arrival at the first work centre. The job is then ranked in the queue according to its slack time in ascending order.

The second definition of slack is called "dynamic slack time". Here slack is defined as the time remaining to the due date, minus the remaining expected flow time through the rest of the system. Of two jobs with identical due dates waiting for service in the same queue, priority is given to the job whose remaining expected flow time is larger. In other words this rule gives the highest priority to the job for which the time remaining to the due date for the finished product less the remaining processing time is a minimum.

Nanot (34) in his study found that the dynamic slack rule generally performed much better than the static slack rule. Gere (8), Hershauer and Ebert (52) also used the dynamic slack rule in their study.

In this research, dynamic slack time is one of the rules investigated.

5. Slack time remaining per operation (STRO).
   This rule is a variation of the slack time rule. Two jobs may have the same slack time, but one could still have a large number of operations to be performed and, hence, has a higher risk of being delayed, than does the other which has only a small number of processes left before being completed. Based on this fact, this rule will give the highest priority to the job with the smallest ratio of slack time to the remaining number of operations. In determining the value of the STO during the research, the numerator is the dynamic slack, not the static slack.

6. Critical Ratio (CR).
   The critical ratio is a variant of dynamic slack time per operation and was very often included in the simulation studies. The development of Critical Ratio Scheduling and its application in some job shops showed advantages over the other rules. This advantage is reflected both in improvements in the dispatching rules and in the application of these scheduling systems to the shop which manufactures items for stock replenishment as well as custom-made-products. The development of Critical Ratio Scheduling and its application in computer based scheduling systems at Twin Disc reported by Wassweiler (60) and Black and Decker reported by Putnam (61) illustrate this advantage. The need for comparison of the performances of Critical Ratio with other rules would seem apparent. Critical Ratio is the ratio between the "allowed" time which remains for manufacturing and the amount of work yet to be completed on order. It can be computed as:

Critical Ratio = (Due date of finished product - date now) / Lead time remaining.

Orders which have fallen behind schedule are indicated by critical ratio values of less than 1.0; with critical ratio values more than one, the jobs are ahead of schedule. If a job has an initial value less than zero it means that the due date for the finished products has already passed. Lead time remaining consists of the sum of remaining machine set-up time, processing times, and an estimate of queue waiting times for each operation to be completed. In practice, queue time estimates are often derived from historical data collected by shops floor feed back system - a system that reports the movement of orders from one machine to the next as they progress through the shop.

The critical ratio rule gives the highest priority to the job with the smallest critical ratio value.

The mathematical models of the priority rules discussed previously are presented in Appendix B (page 173).

<u>Secondary Priority Rules</u>

The procedure for determining the priority of a job normally involves the use of a number of rules. It is necessary to use several rules because a single rule cannot account for all of the criteria which make one job more urgent than another. If more than one rule is used then the priority rules are often arranged in a hierarchy, ties between jobs that exist after application of one rule being resolved by use of subordinate rules.

In relation to this, in the system developed besides rules mentioned previously would be included the secondary priority rules in selecting the most urgent job to process first from a number of jobs which are ready for operation in a certain work centre. This type of priority is set by management according to the following procedure:

- the priority of "S" being given to all standard production orders and "P" to those jobs whose completion on time is of paramount importance.

The procedure for determining the most urgent job in the system developed will be explained in more detail in Chapter V.

IV.7 Operator assignment decision.

Past scheduling research has been largely concerned with the single-constrained job shops (generally in the case of machine-constrained job shops). More recently, studies have recognised and considered the importance of the operator assignment decision rules as well as the dispatching rules in dual-constrained job shops (operator and machine-constrained). Simulation studies of operator and machine-constrained job shops by Nelson (43) (53) and Fryer (57) (55) indicate that shop performance is affected by operator assignment policies as well as by dispatching (priority) rules. Since the previous researches have indicated that the performance of the production system is also affected by operator assignment decisions, the operator assignment decision was included in this research. There are two rules or decisions concerning the operator assignment policy employed during the research, these being:

1. When an operator completes servicing a job on a certain machine, he is available for reassignment to any machine or work centre in the job-shop. This rule is called the "centralised operator reassignment rule" (COR).

2. When an operator completes servicing a job on a certain machine he is available for reassignment only if there are no jobs in the queue at the work centre to which he is presently assigned. This rule is called the "decentralised operator reassignment rule" (DOR).

The two policies discussed above will be included as one of the elements of operating policies considered during the research.

IV.8 Performance criteria used.

The ojective of any scheduling system is to find the sequence of jobs which satisfies certain criteria of performance. According to Blackstone (48) "it cannot be stated too strongly that the only relevant measure of performance for an operating policy is cost effectiveness". Cost is generally avoided because the results would only be applicable to systems with cost structures similar to the one used. Operating policies mainly influence delay costs, inventory costs, and set-up costs, with the major impact on delay costs. Brown (56) pointed out that different industries have typically quite different goals. For some it is investment in work in progress, finished goods and raw materials whereas others (probably most) are more seriously concerned with service to customers - completion of the work on or before the promised delivery date. Furthermore, since the number of simulation studies concerning the scheduling of assembled product is quite limited, there is no widely accepted single criterion or set of criteria to measure the performance of this type of system effectively.

In recognition of these facts, in order to analyse the behaviour of the production system simulated with respect to the different performance criteria, a number of performance measures were selected to be calculated at the end of each scheduling period.
These are:

1. Mean tardiness.
   This criterion represents mean tardiness of orders completed after their due date.

2. Percent tardy.
   Percent tardy represent the proportion of orders completed tardy compared with the total number of orders completed during the scheduling period.

3. Mean work in progress (WIP).
   Mean work in progress can be expressed as follows:

   WIP = (total work content of WIP x queue time of WIP) / (total work content produced).

4. Mean machine utilisation.
   This performance is the ratio of the amount of productive time and total working time available of all the machines at a facility throughout the period of scheduling.

5. Mean operator utilisation.
   Mean operator utilisation is the ratio of the

amount of productive time and total working time available of all operators throughout the period of scheduling.

The mathematical formulation of the performance criteria is represented in Appendix B (page 176).

CHAPTER V

THE REAL TIME SCHEDULING SIMULATION DESIGN SYSTEM

Due to the nature of the simulated production system, a computer simulation written in DBASE III PLUS was developed. The outline flow chart which describes the main steps how the real time scheduling simulation system works is represented in Fig. V.1.

The function of the simulation system is to generate a schedule by using operating policies selected for the research. The system is called Real Time Scheduling System (REALTIS).

The system consists of one main program and six sub programs. Table V.1 briefly explains the names of each program and its main function in the system. Each sub-program consists of several sub-sub-programs, ranging from one to four.

The diagram of programs developed for this system is shown in Fig C.1, Appendix C, page 179. The function of each program in detail, as well as its flow chart showing how it works (the steps of execution) can be described as follows.

V.1 MAINRTS

The outline flow chart of the program is shown in Fig. V.2.

The function of the MAINRTS is to execute the following routines.

- Initialisation of the parameters and variables that

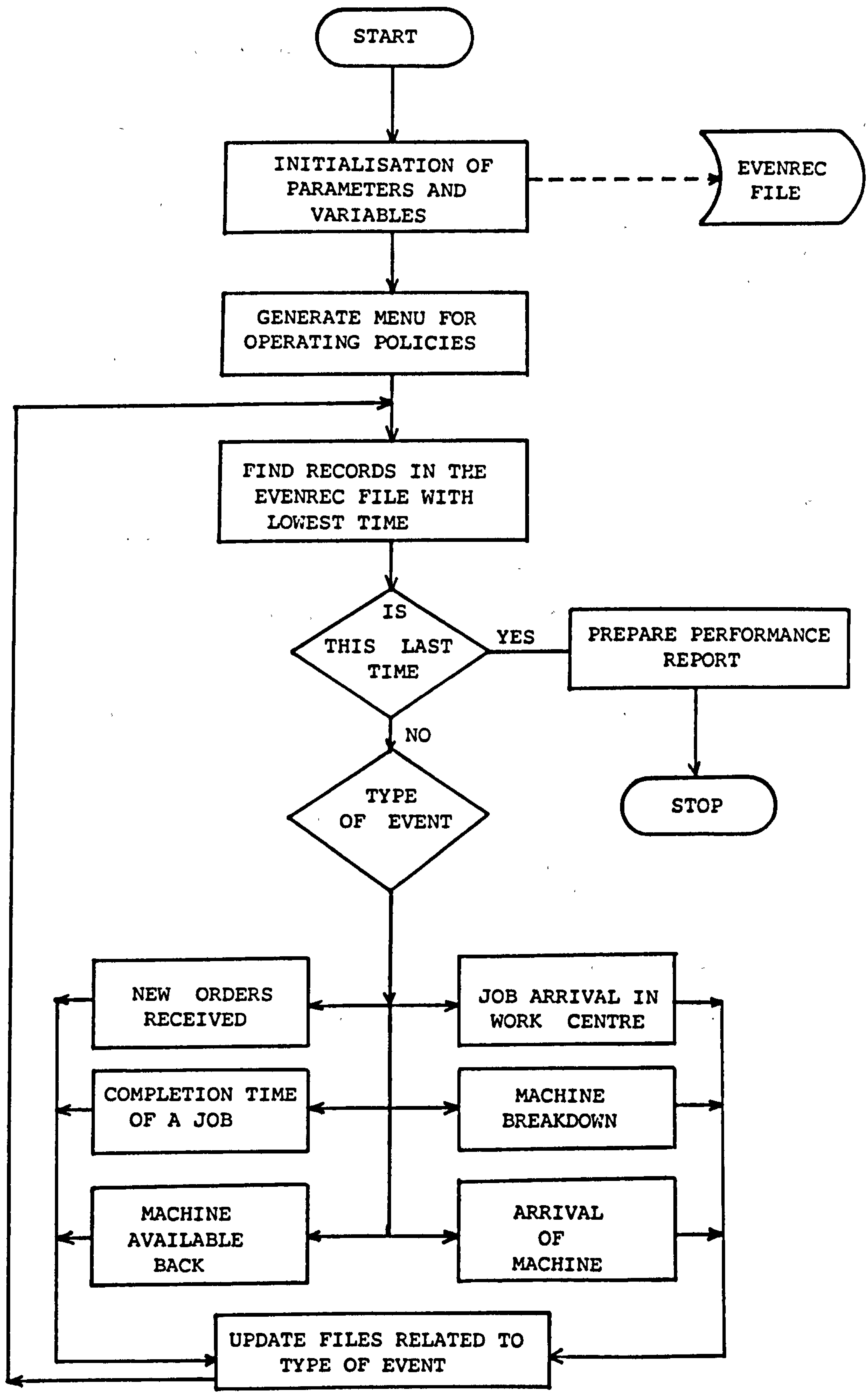


FIG. V.1 : The Outline Flow Chart of REALTIS

Table V.1 The main function of main program and sub-programs of REALTIS

NO	NAME OF PROGRAM	MAIN FUNCTION
1	MAINRTS sub program	- Initialisation of parameters and variables that are used during the simulation period and to generate the menu for choosing operating policy
2	INTILOD sub-program	- To assimilate the incoming orders into the system and to load the job to available machines / facilities
3.	FORWAL sub-program	- To sort the jobs in the queue of each machine and to schedule the jobs on that machine
4	COMRET sub-program	- To process the job just completed from a certain machine and proceed to the next machine (operation)
5	ADAPTIVE sub-program	- To carry out capacity adjustment and load adjustment when new orders arrive
6	DOWN sub-program	- To generate the time when the machine breaks down and to determine the time when a machine affected by breakdown will next be available for work
7	RESULT sub program	- To calculate the performance of the production system at the end of simulation period.

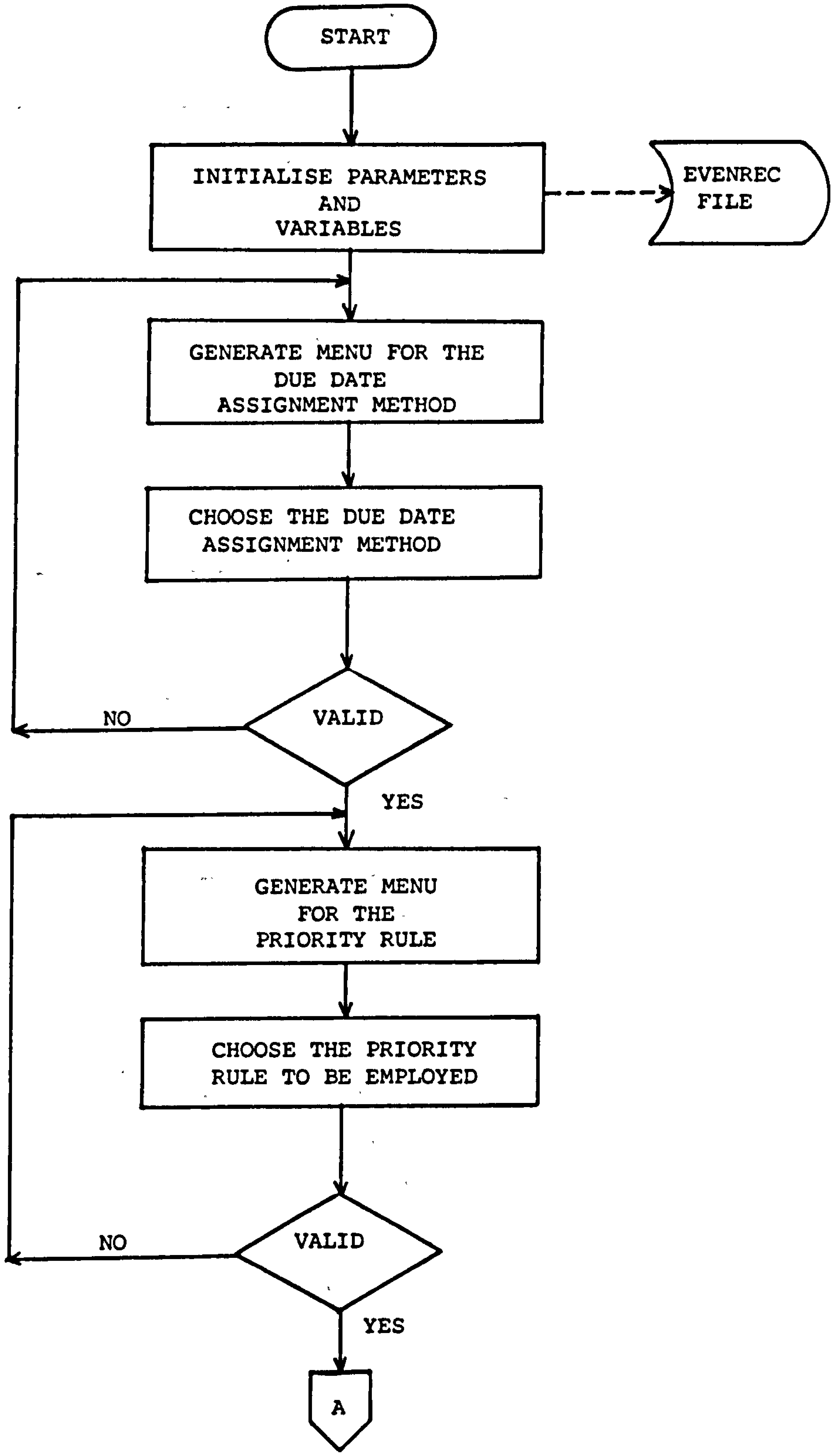
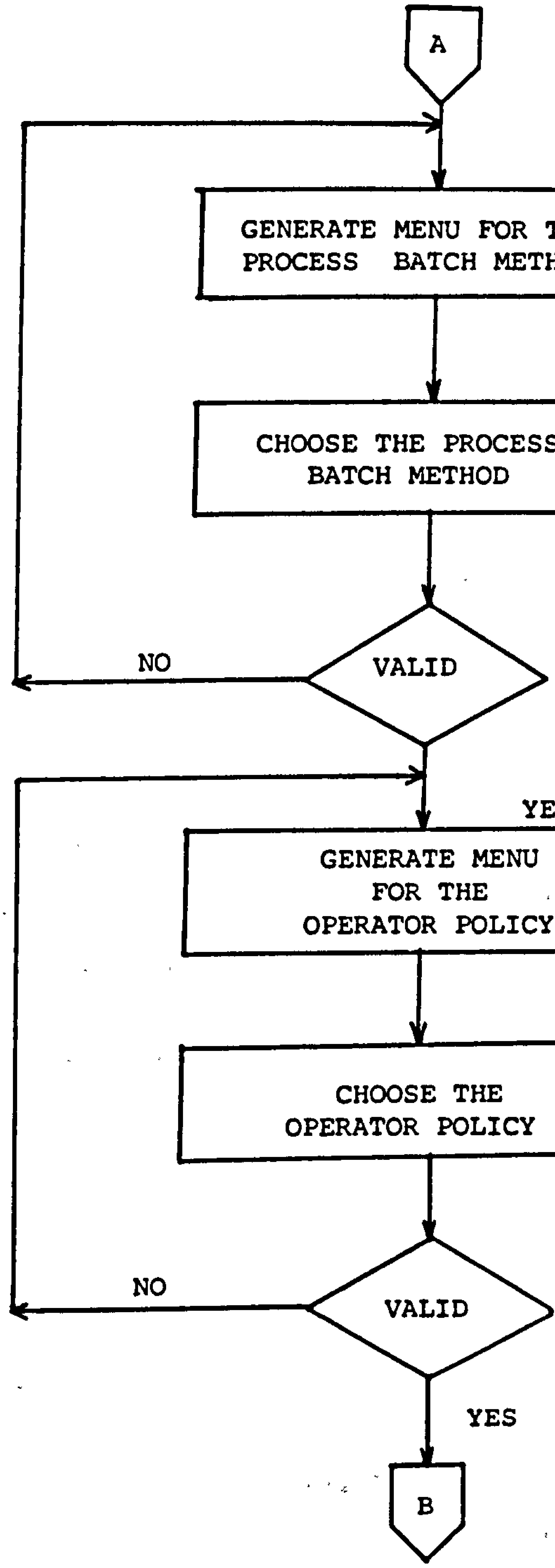
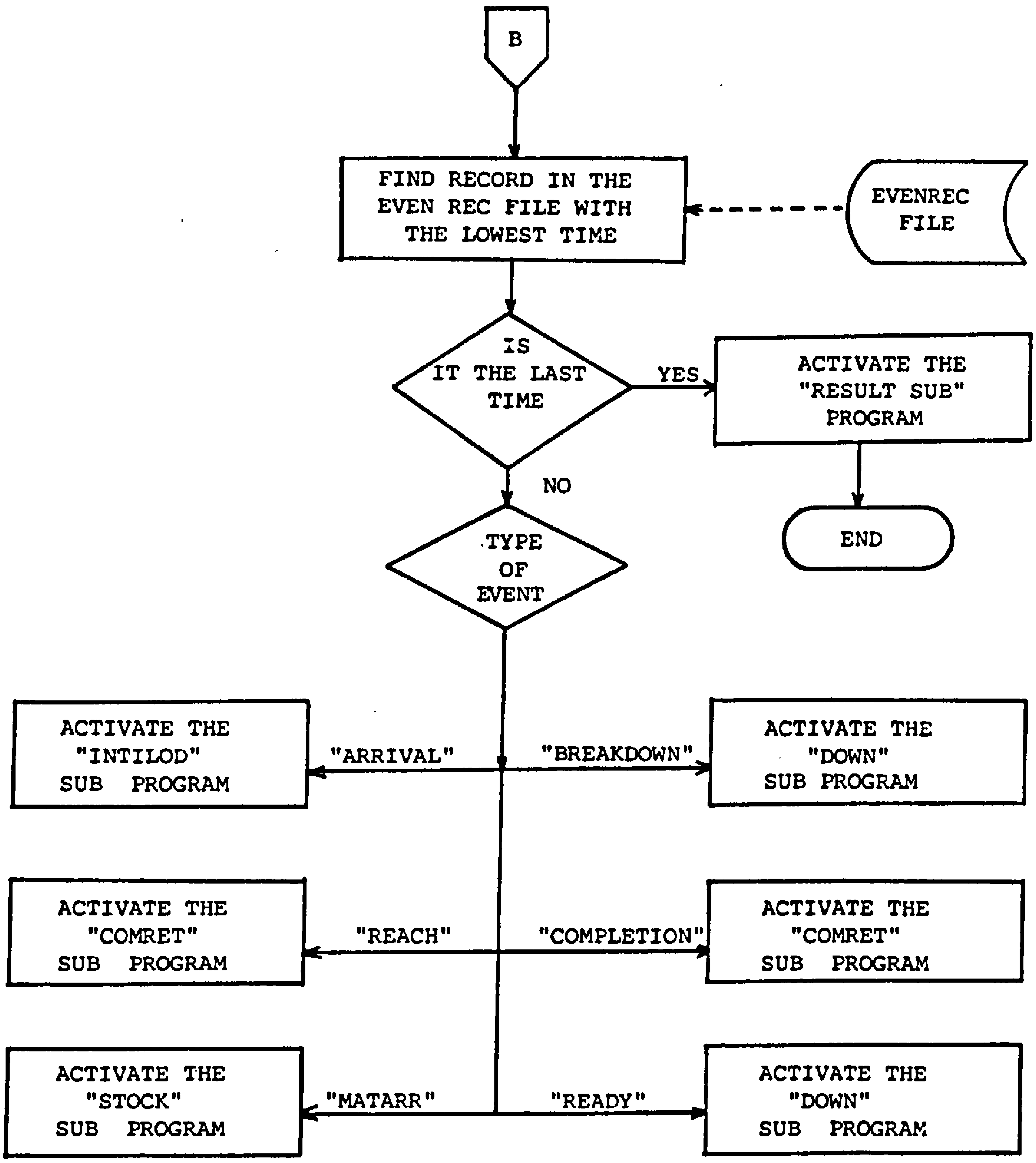


FIG. V.2 : Outline Flow Chart of MAINRTS


A
GENERATE MENU FOR THE PROCESS BATCH METHOD
CHOOSE THE PROCESS BATCH METHOD
VALID
NO
YES
GENERATE MENU FOR THE OPERATOR POLICY
CHOOSE THE OPERATOR POLICY
VALID
NO
YES
B



"ARRIVAL" = The New Orders Received

"REACH" = The Job Arrives at the Next Manufacturing Stage

"MATARR" = The Arrival of Material

"BREAKDOWN" = A Machine Breakdown

"COMPLETION" = The Completion of a Job

"READY" = A Machine Affected by Breakdown is Ready for Operation are used, such as current time and the end of run time.

- Generate the menu of operating policies. There are four sets of options subsequently displayed on the screen. The first is concerned with the due date assignment methods options to be used in the simulation.

Those options are:

1. Total Work Content (TWC)

2. Material Requirements Planning (MRP).

Meanwhile, the second set will contain the options concerning with the priority rules to be employed.

These options are:

1. Critical Ratio (CR)

2. First come first served (FCFS)

3. Shortest imminent operation time (SIOT)

4. Earliest due date (EDD)

5. Slack time remaining (STR)

6. Slack time per remaining operation (STRO).

In the third set, the options regarding the process batch method would be found. These are,

1. Fixed process batch (FPB)

2. Variable process batch (VPB)

The last set of options will appear on the screen concerned with the operator reassignment method.

1. Centralised operator reassignment (COR).

2. Decentralised operator reassignment (DOR).

- To manipulate the EVENREC file; in this file each event that occurs during the simulation would be recorded. Table V.2 describes one example of the EVENREC file.

V.2 INTILOD

The function of this program is to generate the incoming orders and to load the available orders to the different machines in a certain period of time by considering the availability of capacity and material. The outline flow process chart of this program is shown in Fig. V.3. INTILOD works according to the following steps.

<u>Step 1 Generate incoming orders</u>

As previously mentioned, the order arrival time is generated from an exponential distribution while the order size is based on the uniform distribution. In order to carry out this process, the INORDER sub-sub-program was developed. During the execution of this program, the ORDSIZE file (Table V.3) containing the specification of the product produced by the system is manipulated. Once this program has been executed the relevant information for each order would be set

Table V.2 An example of the EVENREC file

EVENT TIME	TYPE OF EVENT	ORD. NO.	PART CODE	QTY UNIT	O/P NO	W/C NO	M/C NO	PROD. TIME hrs	STOCK POINT	ORD. SIZE
881736	reach	0146	B718	26	3	409		10		
881737	arrival	0149								
881738	reach	0103	M100/2	27	2	403		24		
881739	completion	0088	A302	22	6	409	1	10		
881741	breakdown					406	1			
881742	ready					410	1			
881743	completion	0097	M100/3	25	2	403	2	22		
881745	completion	0148	A302	22	1	410	2	17		
881752	matarr		P930						224	1000

Notes.

EVENT TIME: Indicates the time when an event occurs.

881752 = Hour 2, Day 5, Week 17, in year 1988

TYPE OF EVENT: The type of event that occurs. There are six types of event that occur during the simulation. These are,

matarr = the arrival of material (raw material, bought out item)

completion = completion of job

arrival = new orders received

reach = job arrival in the queue of a work centre

breakdown = machine breakdown

ready = a machine affected by breakdown will next be available for work

STOCK POINT: The pointer that can be used to find the corresponding record in the STOCK file for updating process in accordance with the "matarr" event.

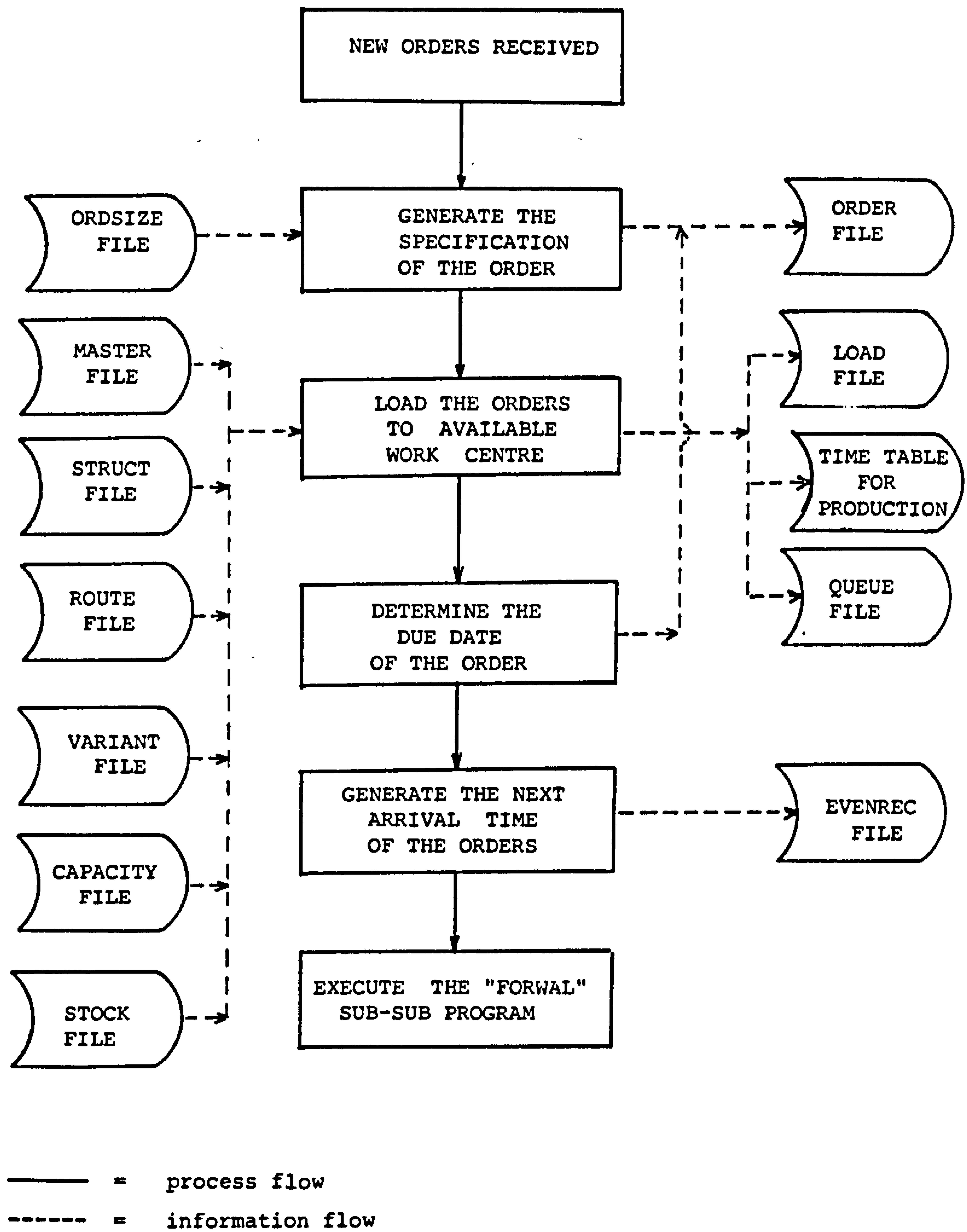


FIG. V.3 : Outline Flow Chart of INTILOD Sub-program

Table V.3 The ORDSIZE File

TYPE OF PRODUCT	MINIMUM ORDER SIZE [unit]	MAXIMUM ORDER SIZE [unit]
Top mixer size 1	25	30
Top mixer size 2	25	30
Top mixer size 3	25	30
Side mixer size 1	20	25
Side mixer size 2	20	25
Side mixer size 3	20	25
Sub-assembly	25	30
Top mixer cage	12	16
Side mixer cage	16	20
Impeller	25	35
Bearing Cover	30	25
Coupling	20	25

up. The information resulting from the execution of INORDER is order number, order code, order quantity, arrival date, priorities set by management for the order, part code, and specification of the order. This information is transferred to the ORDER file (Table V.4).

Step 2 Load the orders to work centre

As orders are generated, the INTILOD program carries out the following routines:

- Set up load file and determines a time table for production for each order. In order to carry out this routine the following files have been created:

  1. MASTER FILE (Table C.1, Appendix C, Page 180). This file contains the information regarding the part code of products to be made, the parent pointer, stock pointer and route pointer of each product which is produced by the job shop. The use of the pointers is explained in Appendix C page 182.

  2. STRUCT FILE (Table C.2, Appendix C, page 184). This file contains the information concerned with the address pointer, the parent code, sub-item code, previous sub-item pointer, next sub-item pointer and the quantity of sub-item in order to make one unit product.

  3. ROUTE FILE (Table C.3, Appendix C, page 188). This file contains the code of the part to be made, the level of the part in the product structure, operation number, work centre number/name where the part is to be processed, the set up time, the standard time in order to perform the appropriate

Table V.4 An example of the ORDER file

ORDER NO	ITEM CODE	QUANT [unit]	ARRIVAL DATE	DUE DATE	PRIORITY
0088	M214/2S24	22	881115	882435	S
0097	M124/3M	25	881211	882628	S
0103	M132/2M	27	881227	882731	P
0146	SA810B/3M	26	881552	882517	S
0148	M214/2S	22	881614	883435	S

<u>Notes</u>

ITEM CODE: Indicates the specification of the customer order.

M214/2S24 = the second size of Top mixer having one 4-bladed impeller, the shaft and impeller being fabricated from stainless steel, the effective length of the shaft being 24 inches.

ARRIVAL DATE: The arrival date of the order.

DUE DATE: The due date on which the finished product is to be delivered to the customer.

PRIORITY: The priority set by management:

P = priority order

S = standard order.

operation on one unit part, the transit time needed in order to transfer the part to the next work centre for next operation, and the number of the work centre where the next operation will be performed.

4. VARIANT FILE (Table C.4, Appendix C, page 191). As previously mentioned, the products that are produced by the job shop vary in terms of size, number of impellers and number of blades. In relation to this, the VARIANT file has been developed which contains the part code of the item to be made, the alternatives of size, number of impellers, number of blades and material.

5. CAPACITY FILE (Table C.5, Appendix C, page 193). The CAPACITY file contains the basic information on the capacity available in each work centre and the capacity already allocated to jobs in each time period.

6. STOCK FILE (Table C.6, Appendix C, page 194). The STOCK file would be used to check the availability of materials and bought-out items when the loading and scheduling processes are carried out. The file contains the part codes of starting materials and bought-out items, stock pointers, the quantity of materials on hand, on order, potential stock alloctions and free stock.

For maintenance of these files, several sub-sub-programs have also been developed in order to support the INTILOD in setting up the LOAD file and determining the time table for production. These are:

1. ALLOCATE; this has the function of allocating a

job to the appropriate work centres according to its routing and availability of capacity at the work centres.

2. STAGE; by means of this program the progress of each job can be monitored.

3. LOOKCAP; performs the function of checking whether or not the capacity of a work centre needed in a certain period of time is available and sufficient for processing a potential job.

4. STOCKC; this program was developed in order to carry out some further tasks. These are:

- to check the availability of starting materials and bought out items in the STOCK file and to allocate the requirements for the stock items to the order;

- to check whether or not the replenishment order of a stock item has been released. The replenishment order of a stock then would be released when the allocated quantity of a stock item subtracted from the free stock is below the reorder level for the item;

- to update the STOCK file in relation to the "matarr" events.

5. MASA; its function is to estimate the starting time and finishing time for processing of a certain job.

6. FILLOAD; this program was developed in order to enable the transfer of relevant information obtained from the execution INTILOD, ALLOCATE, STAGE, LOOKCAP, STOCKC, MASA into the LOAD file, the timetable for

production, and the QUEUE file. An example of each of the files is shown in Table V.5, Table V.6 and Table V.7.

The relevant information to be transferred into the LOAD file is the load week of the job, order number, part code, quantity, operation number, the balance of the work centre capacity, capacity required, the next work centre number and the priority set by management. The relevant information, such as order number, part code, operation number, work centre number, production time, estimated queue time, transit time, and estimated start time and finish time of operation would be transferred into the timetable for production. Meanwhile, in the QUEUE file would be transferred the necessary information concerning jobs which are eligible to be processed according to their operating sequence, such as the arrival time at the corresponding work centre, order number, production time, etc.

Step 3. Determine the Due Date of the Finished Product

INTILOD will assign the due date of the finished product by applying the due date assignment methods which have been explained in Chapter IV and transfers the result to the ORDER file.

Step 4. Generate the Next Arrival Time of New Orders

Generate the arrival time of the new orders by using the distribution already mentioned in Chapter IV and transfer the results into the EVENREC File.

Table V.5 The LOAD file of the work centre 406 [SAW]

W/C : 406
[S A W]

LOADED WEEK	ORDER NO	PART CODE	OP NO	PRIO RITY	QUAN TITY	CAP REQ hrs	BAL OF CAP hrs	ARR DATE	DUE DATE
8804	0001	B721	1	S	63	15	93	88041	88095
8804	0001	B716	1	S	63	8	85	88041	88095
8804	0001	B711	1	S	21	2	83	88041	88095
8804	0001	A342	1	S	21	3	80	88041	88095
8804	0003	B721	1	S	25	6	74	88041	88053
8804	0003	B716	1	S	25	3	71	88041	88053

Note

LOADED WEEK = the week when the job is loaded to the work centre

8804 = week 4 in year 1988

Table V.6 The time table for production

ORD NO	PART CODE	QTY	OP NO	W/C NO	PROD TIME hrs	TRANS TIME hrs	QUEUE TIME hrs	START TIME	FINISH TIME
0001	M200/2	21	4	401	12.60	8	0	880942	880957
0001	M200/2	21	3	402	17.50	8	13	880911	880932
0001	M200/2	21	2	403	18.55	8	15	880811	880834
0001	M200/2	21	1	404	10.50	8	0	880717	880732
0001	A302	21	7	412	2.10	8	0	880636	880638
0001	A302	21	6	409	9.77	8	0	880614	880626
0001	A302	21	5	405	9.22	8	0	880543	880554
0001	A302	21	4	411	1.00	8	0	880532	880533
0001	A302	21	3	408	1.73	8	0	880518	880522
0001	A302	21	2	414	15.27	8	0	880441	880458
0001	A302	21	1	410	16.20	8	0	880411	880431
0001	A332	21	3	411	0.55	8	0	880434	880434
0001	A332	21	2	408	0.55	8	0	880423	880424
0001	A332	21	1	413	2.21	8	0	880411	880413
0001	A342	21	3	405	2.35	8	0	880443	880446
0001	A342	21	2	408	3.13	8	0	880428	880433
0001	A342	21	1	406	2.80	8	4	880415	880418
0001	SA800/X	21	1	405	4.15	8	0	880653	880657
0001	B711	21	2	405	0.23	8	0	880427	880427
0001	B711	21	1	406	2.27	8	4	880415	880417
0001	A3224	63	1	407	26.25	8	10	880611	880643
0001	B716	63	3	409	21.67	8	4	880511	880537
0001	B716	63	2	408	9.65	8	0	880434	880446
0001	B716	63	1	406	8.40	8	2	880413	880424
0001	B721	63	1	406	14.70	8	0	880411	880428
0002	A302	16	7	412	1.60	8	0	880632	880634
0002	A302	16	6	409	7.60	8	4	880613	880622
0002	A302	16	5	405	7.38	8	0	880537	880546
0002	A302	16	4	411	0.83	8	0	880526	880527
0002	A302	16	3	408	1.40	8	0	880515	880516
0002	A302	16	2	414	12.10	8	0	880438	880455
0002	A302	16	1	410	12.78	8	3	880414	880428
0003	A3214	25	1	407	10.42	8	0	880517	880531
0003	B716	25	3	409	9.00	8	0	880446	880457
0003	B716	25	2	408	3.95	8	0	880432	880436
0003	B716	25	1	406	3.33	8	6	880417	880422
0003	B721	25	1	406	5.83	8	5	880416	880424

Table V.7 The QUEUE file of work centre 407

CURRENT TIME : 88241
W/C NO.: 407 [WELD]

ARRIV TIME	ORD NO	PART CODE	OP NO	P	DUE DATE	OP DAY REM	M	T	D	O	PROC BAT	PROD TIME hrs	CRITIC RATIO	NEXT W/C
8821	0088	A3224	1	S	88252						22	9.17		405
8821	0085	A3214	1	S	88261						23	9.58		405
8821	0094	A3232	1	S	88273						23	5.75		405
8821	0091	A3224	1	S	88262						63	26.25		405
8822	0097	A3234	1	P	88291						50	20.83		405
8822	0100	A3232	1	S	88324						52	13.00		405
8822	0115	A3214	1	S	88291						23	9.58		405
8823	0109	A3214	1	S	88285						52	21.67		405
8823	0103	A3222	1	S	88332						81	20.25		405
8823	0082	A3214	1	S	88292						48	20.00		405
8823	0123	A3214	1	S	88301						25	10.42		405
8824	0135	A3224	1	P	88311						30	12.50		405
8824	0127	A3234	1	S	88301						50	20.83		405
8824	0121	A3224	1	P	88301						63	26.25		405

Notes

ARRIV TIME = arrival time of the job at the work centre

P = priority set by management

DUE DATE = due date of the finished product

OP DAY REM = number of days required to complete the finished product, including the current operation time

M = materials

T = tools

D = drawings

O = others

PROC BAT = the batch size of the part to be processed

NEXT W/C = work centre where the next operation will be performed

V.3 FORWAL

The function of the program is to schedule the jobs which queue at a work centre. The program will be activated after the execution of the INTILOD or the COMRET sub-program.

The outline flow chart of the program is shown in Fig. V.4. FORWAL works according to the following steps:

Step 1. Check the Availability of the Requirements Required in Order to do the Job

Check whether or not all the requirements required such as materials, tools and drawings, in order to process the first operation or part of the order loaded are available. To check the availability of material, the program works as follows.

- If the first operation to be carried out on a job, the material has been issued from the stores.

- A single material job is considered to be marshalled when its previous manufacturing stage has been completed, or, if it is an assembly operation to be carried out, when the parts to be assembled have been completed and the bought-out items required have been issued from the stores.

To check the availability of material, the STOCK file and the MATREQ file are manipulated.

A machine/work centre is considered available when the status of the machine according to record in the WCENTRE file (Table V.12) is idle. Likewise an

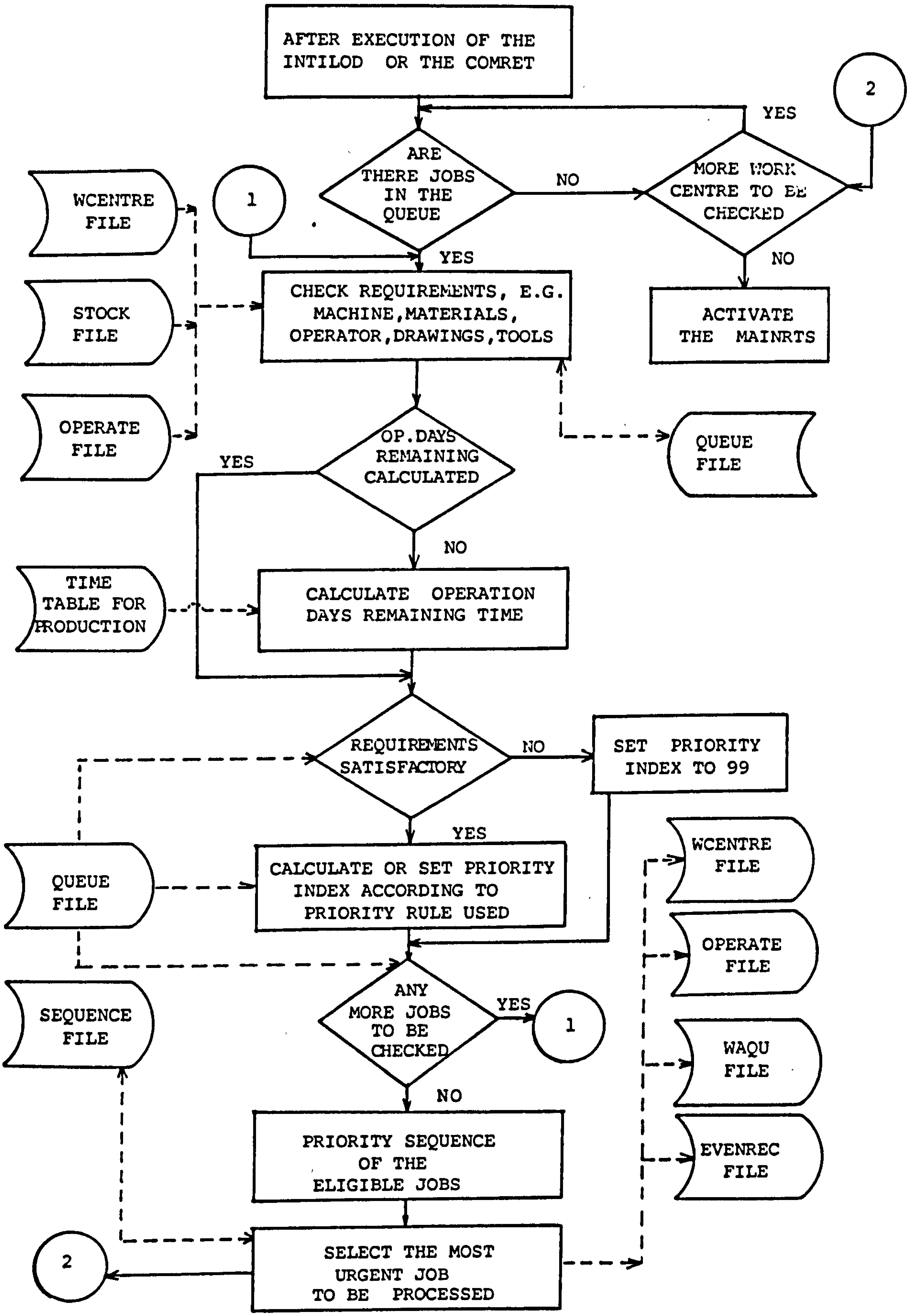


FIG. V.4 : Outline Flow Chart of FORWAL

operator could be assigned for the job if his/her status according to the corresponding record in the OPERAT file (Table V.13) is "not duty". The system developed does not provide the files regarding tools and drawings. However, in order to make the system more realistic, the availability of both tools and materials is carried out by generating a random number where its value ranging from zero to one. If the random number is less than or equal to 0.05, it is assumed that the tools and drawings are not available.

The availability of a job for scheduling is indicated by the set of asterisks against the job in the QUEUE file when materials, machine, operator tools and drawings are available.

Step 2. Calculate the Operation Days Remaining of Each Job (if it has not been calculated) in the QUEUE File

The operation days remaining of a job is number of days required to complete the finished product, including the current operation time of the job. In order to carry out this step, the program would manipulate the time table for production.

Step 3. Calculate the Priority Index of Jobs which are ready for Operation as Indicated by having a Complete Set of Asterisks

Calculation of the priority index is based on the priority rule chosen for the simulation. Following, is given an example of the calculation of the critical ratio which is being used, in this case, as the priority rule for each job. The example is given for order No. 0094 and part code A3232 in Table V.7.

Critical ratio (CR) = (the due date of finished product - current date)/ (operation days remaining)

$$= \frac{88273 - 88241}{14}$$

$$= 1.214$$

Note:

88273 = Day 3, Week 27 in Year 88

88241 = Day 1, Week 24 in Year 88

If there is one or more jobs which are ready for operation, the execution of the program continues to step 4, otherwise it proceeds with step 10.

The procedure of Steps 1-3 is presented in Table V.8.

Step 4. Create the SEQUENCE File

Jobs which are available for operation in the QUEUE file, as indicated by having a complete set of asterisks, are copied into the SEQUENCE file where they are sorted into priority sequence. The jobs sequence is determined by sorting the jobs,

a) by management priority;

b) within the management priority by priority index.

Following, two examples of the sequence procedure are given with respect to the priority rule employed:

1.The priority sequence procedure if the critical ratio (CR) is used as the priority rule.

Table V.8 QUEUE FILE [1)]

CURR TIME : 88241
W/C NO : 407 [WELD]

ARRIV TIME	ORD NO	PART CODE	OP NO	P	DUE DATE	OP DAY REM	M	T	D	O	PROC BAT	PROD TIME hrs	CRITIC RATIO	NEXT W/C
8821	0088	A3224	1	S	88252	14	*	*	*	*	22	9.17	0.429	405
8821	0085	A3214	1	S	88261	14	*	*	*	*	23	9.58	0.714	405
8821	0094	A3232	1	S	88273	14	*	*	*	*	23	5.75	1.214	405
8821	0091	A3224	1	S	88262	16	*	*	*	*	63	26.25	0.688	405
8822	0097	A3234	1	P	88291	17	*	*	*	*	50	20.83	1.471	405
8822	0100	A3232	1	S	88324	16	-	-	*	*	52	13.00	99.000	405
8822	0115	A3214	1	S	88291	14	*	*	*	*	23	9.58	1.786	405
8823	0109	A3214	1	S	88285	17	*	*	*	*	52	21.67	1.412	405
8823	0103	A3222	1	S	88332	17	-	*	*	*	81	20.25	99.000	405
8823	0082	A3214	1	S	88292	16	*	*	*	*	48	20.00	1.625	405
8823	0123	A3214	1	S	88301	14	*	*	*	*	25	10.42	2.143	405
8824	0135	A3224	1	P	88311	17	*	*	*	*	30	12.50	2.059	405
8824	0127	A3234	1	S	88301	17	*	*	*	*	50	20.83	1.765	405
8824	0121	A3224	1	P	88301	16	*	*	*	*	63	26.25	1.875	405

[1)] The procedure of checking the availability of a job for scheduling

In order to ensure that jobs with priorities set by management are not produced much earlier than they are required at the expense of standard jobs which are already running behind program, any standard jobs having a critical ratio less that unity are pushed ahead of priority jobs which have critical ratios higher than a preset value, in this case arbitrarily set at 1.200. The PRISEQ-A sub-program was developed in order to support the FORWAL in carrying out this procedure. The procedure of creating the SEQUENCE file is presented in Table V.9.

2.The priority sequence procedure if any one of the other test rules chosen is to be the priority rule.

In order to ensure that jobs with priorities set by management are not much tardy, any priority jobs which are already running behind schedule are pushed ahead of standard jobs which are also already behind schedule. In order to know whether or not a job is already behind schedule, the current date was compared with the stage date in the time table for production. A job is behind schedule if the current date is later than the stage date in the time table. In order to carry out this procedure the PRISEQ-B sub-sub-program was developed. An example of the procedure where the shortest imminent operation time is the priority rule is depicted in Table V.10.

<u>Step 5. Selection of the Most Urgent Job from the Queue</u>

Once the jobs have been sorted into priority sequence in the SEQUENCE file, the JOBSED sub-sub-program that was developed in order to support the FORWAL in carrying out this step is activated to select the most

Table V.9 SEQUENCE FILE [1)]

CURR.TIME : 88241
W/C NO. : 407 (WELD)

ORDER NO	PART CODE	O/P NO	PROCESS BATCH [unit]	PRODUCT TIME [hrs]	PRIORITY	CRITICAL RATIO
0088	A3224	1	22	9.17	S	0.429
0091	A3224	1	63	26.25	S	0.688
0085	A3214	1	23	9.58	S	0.714
0097	A3234	1	50	20.83	P	1.471
0121	A3224	1	63	26.25	P	1.875
0135	A3224	1	30	12.50	P	2.059
0094	A3232	1	23	5.75	S	1.214
0109	A3214	1	52	21.67	S	1.412
0082	A3214	1	48	20.00	S	1.625
0127	A3234	1	50	20.83	S	1.765
0115	A3214	1	23	9.58	S	1.786
0123	A3214	1	25	10.42	S	2.143

1) Priority sequence of the jobs for scheduling where the critical ratio (CR) is the priority rule

TABLE V.10 SEQUENCE FILE

CURR. TIME : 882423

W/C No.: 407 [WELD]

ORDER No.	PART CODE	O/P No.	PROCESS BATCH [UNIT]	PRODUCT TIME [HRS]	PRIO RITY	START DATE [PLANNED]	STATUS OF THE JOB
0135	A3224	1	30	12.50	P	882143	Y
0123	A3214	1	25	10.42	S	882044	Y
0082	A3214	1	48	20.00	S	882236	Y
0094	A3232	1	23	5.75	S	882445	N
0088	A3224	1	22	9.17	S	882427	N
0085	A3214	1	23	9.58	S	882426	N
0115	A3214	1	23	9.58	S	882734	N
0097	A3234	1	50	20.83	P	882542	N
0127	A3234	1	50	20.83	S	883017	N
0109	A3224	1	23	21.67	S	882718	N
0091	A3224	1	63	26.25	S	882444	N
0121	A3224	1	63	26.25	P	882824	N

NOTE: Y = The job is behind schedule
N = The job is on schedule

1) Priority sequence of jobs for scheduling where the shortest imminent operation time (SIOT) is the priority rule.

urgent job among the jobs in the SEQUENCE file. In the real world situation, although a job has been considered as being the most urgent job to be processed immediately, there is a possibility that this job cannot be processed due to some reason such as:

- the job is unsuitable for this machine; i.e. error in routing;

- operator is unsuitable to perform the job; i.e. lack of skill;

- technological reason; i.e. error in drawing;

- etc.

In the simulation, the reason which caused the most urgent job according to the SEQUENCE file not to be processed immediately could not be detected as in the real world situation. However, the system provides a way in which the effect of rejection of a job due to one or more of the above reasons during the simulation could be taken into account. During the simulation, the JOBSED would generate a random number which has a value ranging from zero to one. When the random number is equal to or less than 0.05 the most urgent job cannot be processed due to one or more of the above reasons.

In consequence of this, the next job in the SEQUENCE file becomes the most urgent job. Conversely, if the random number is greater than 0.05 the most urgent job would be processed immediately and the program will continue to step 6.

Step 6. Calculate the Completion Time of the Job

The production time of a job shown in the time table for production was calculated based on the average production time that was found in the ROUTE file. Assuming the production time follows a uniform distribution, then the actual production of a job may be calculated as follows.

$$apt = (1 - k + 2k \times RND)pt$$

where,

apt = the actual production time

k = the factor that is used to determine the maximum and the minimum production times; during the simulation the value of k is set at 0.05

pt = the production time of the job in hrs; [set up time + quantity x standard unit time]

RND = random number which its value ranging from 0 to 1.

Further, with k = 0.05 the completion time of job can be calculated as follows.

$$cl = cd + (0.95 + 0.1RND)pt$$

where,

cl = the completion time of the job

cd = current date.

The estimated completion time along with the relevant information concerning the job is transferred into the EVENREC file.

Step 7. Calculate the Actual Queue Time (if any)

The actual queue time can be calculated by subtracting the arrival time of the job to the work centre from the start time when the job to be processed. The actual queue time would be stored in the WAQU file (Table V.11). The WAQU file has the function of maintaining the record of the queue time of the job.

Step 8. Calculate the Idle Time of the Machine

The status of the machine that is chosen to perform the job is set to "busy" by updating the record concerning the machine in the WCENTRE file. Further, calculate the idle time of the machine (if any) by subtracting the last time when the machine finished its previous job (this is recorded in the WCENTRE file) from the time when the machine starts to perform the next job and add to the cumulative idle time stored in the WCENTRE FILE (Table V.12).

Step 9. Calculate the Idle Time of the Operation

The status of the operator who is assigned to operate the machine is set to "duty" by updating the record status of the operator in the OPERAT file. Further, calculate the idle time of the operator by subtracting the last time when he/she finished the latest task (recorded in the OPERAT file) to the time when he/she starts to perform the next task and add to the cumulative idle time stored in the OPERAT file (Table V.13).

TABLE V.11 WAQU FILE

ORDER NO.	PART CODE	W/C NO.	O/P NO.	WAIT TIME [hrs]	QUEUE TIME [hrs]	WORK CONT [hrs]	WORK CONT x WAIT TIME	WORK CONT x QUEUE TIME
0017	A302	410	1	0	7	0	0	0
0010	A343	408	2	0	4	4	0	16
0016	B716	406	1	0	9	0	0	0
0013	A342	408	2	0	4	4	0	16
0015	B721	406	1	0	11	0	0	0
0010	B712	406	1	0	12	0	0	0
0014	A303	410	1	0	13	0	0	0
0020	B718	412	1	0	14	0	0	0
0019	A331	413	1	0	14	0	0	0
0015	B716	408	2	0	2	5	0	10
0019	B716	406	1	0	15	0	0	0
0013	A332	411	3	0	1	3	0	3
0013	B716	408	2	0	1	11	0	11
0010	A333	411	3	0	1	3	0	3
0016	B721	406	1	0	16	0	0	0
0004	B722	407	1	17	0	5	85	0
0004	A3232	407	1	0	2	22	0	44
0013	B711	405	2	0	1	3	0	3
0007	B712	406	1	0	0	22	0	0
0020	B722	412	1	0	16	0	0	0
0001	A302	406	3	0	7	31	0	217
0007	A313	408	2	0	7	25	0	175
0016	A342	406	1	0	18	0	0	0
0019	B721	406	1	0	10	0	0	0
0016	B711	406	1	0	11	0	0	0
0002	A302	405	5	0	1	28	0	28
0010	A313	408	2	0	2	25	0	50
0022	A331	413	1	0	18	0	0	0
0018	B718	408	2	0	6	5	0	30
0020	B742	412	1	0	16	0	0	0
0001	B721	407	1	20	0	15	300	0
0010	B712	405	2	0	2	3	0	6
0004	A303	408	3	0	2	34	0	68
0013	A312	408	2	0	1	26	0	26
0018	B722	406	1	0	15	0	0	0
0004	B712	405	1	17	0	3	51	0

TABLE V.12 WCENTRE FILE
CURRENT TIME : 881642

W/C No.	M/C No.	M/C COND.	ORD. No.	PART CODE	PROC. BATCH	OP. No.	CUMUL. IDLE hrs	LAST COMP. TIME
401	1	busy	0055	M200/1	23	4	26	881613
402	1	idle	-	-	0		87	881554
402	2	idle	-	-	0		69	881456
403	1	idle	-	-	0		78	881614
403	2	busy	0067	M100/3	25	2	118	881421
404	1	busy	0073	M100/2	27	1	73	881615
405	1	busy	0110	SA800/X	28	1	34	881616
405	2	busy	0106	A312	28	4	39	881615
406	1	busy	0142	B721	48	1	11	881559
406	2	busy	0142	A341	24	1	9	881618
406	3	busy	0150	b721	29	1	16	881615
407	1	busy	0120	A3224	29	1	1	881559
407	2	busy	0116	A323B	26	1	0	881544
408	1	busy	0146	B718	26	2	20	881622
408	2	busy	0142	B716	48	2	33	881614
409	1	busy	0122	A302	16	6	1	881622
409	2	busy	0138	B718	34	3	4	881612
409	3	busy	0103	A312	27	5	9	881618
410	1	busy	0147	A312	12	1	5	881559
410	2	busy	0133	A312	27	1	1	881545
410	3	busy	0130	A313	26	1	4	881542
411	1	idle	-	-	0		121	881622
412	1	busy	0127	B712	25	1	53	881622
413	1	idle	-	-	0		210	881618
414	1	busy	0137	A302	19	2	58	881613
414	2	busy	0088	A302	22	2	65	881615
415	1	busy	0146	B722	26	2	206	881621

TABLE V.13 OPERAT FILE

CURRENT TIME 881641

OPERAT OR No.	W/C LOCAT.	STATUS	ASSIGN TO W/C No.	M/C No.	CUMUL. IDLE hrs	LAST COMP TIME
1	401	duty	401	1	0	881613
2	402	duty	406	2	0	881618
3	402	duty	407	2	0	881544
4	403	duty	409	2	1	881612
5	403	duty	409	3	0	881618
6	404	not duty			1	881614
7	405	duty	407	1	1	881559
8	405	durt	404	1	3	881615
9	406	not duty			1	881615
10	406	duty	409	1	1	881622
11	406	not duty			2	881615
12	407	duty	414	2	4	881618
13	407	duty	405	1	4	881621
14	408	duty	415	1	3	881621
15	408	no duty			2	881545
16	409	duty	414	1	1	881613
17	409	not duty			6	881555
18	410	not duty			1	881559
19	410	duty	410	1	2	881559
20	410	duty	408	1	5	881622
21	411	duty	412	1	16	881622
22	412	duty	410	3	0	881542
23	413	not duty			4	881613
24	414	not duty			10	881615
25	415	not duty			7	881514

Step 10.

Repeat Step 1 if there are more jobs in the queue at the other work centres which are eligible to be scheduled, otherwise execute the MAINRTS.

V.4 COMRET

The outline flow chart of the COMRET sub-program is presented in Fig. V.5. The program will be activated by the occurrence of any one of the following two events:

- completion of a job on a machine,
- the arrival of a job in the queue at a work centre.

Completion of a job on a machine.

The completion of a job on a machine activates COMRET according to the following steps.

Step 1. Estimate the arrival time of the job to the next manufacturing stage or, in the case of a finished product the arrival time of the product to the customer. The estimated arrival time can be calculated by equations:

$$at = ct + tr$$

where,

at = arrival time of the job to the next manufacturing stage or to the customer

ct = completion time

tr = transit time

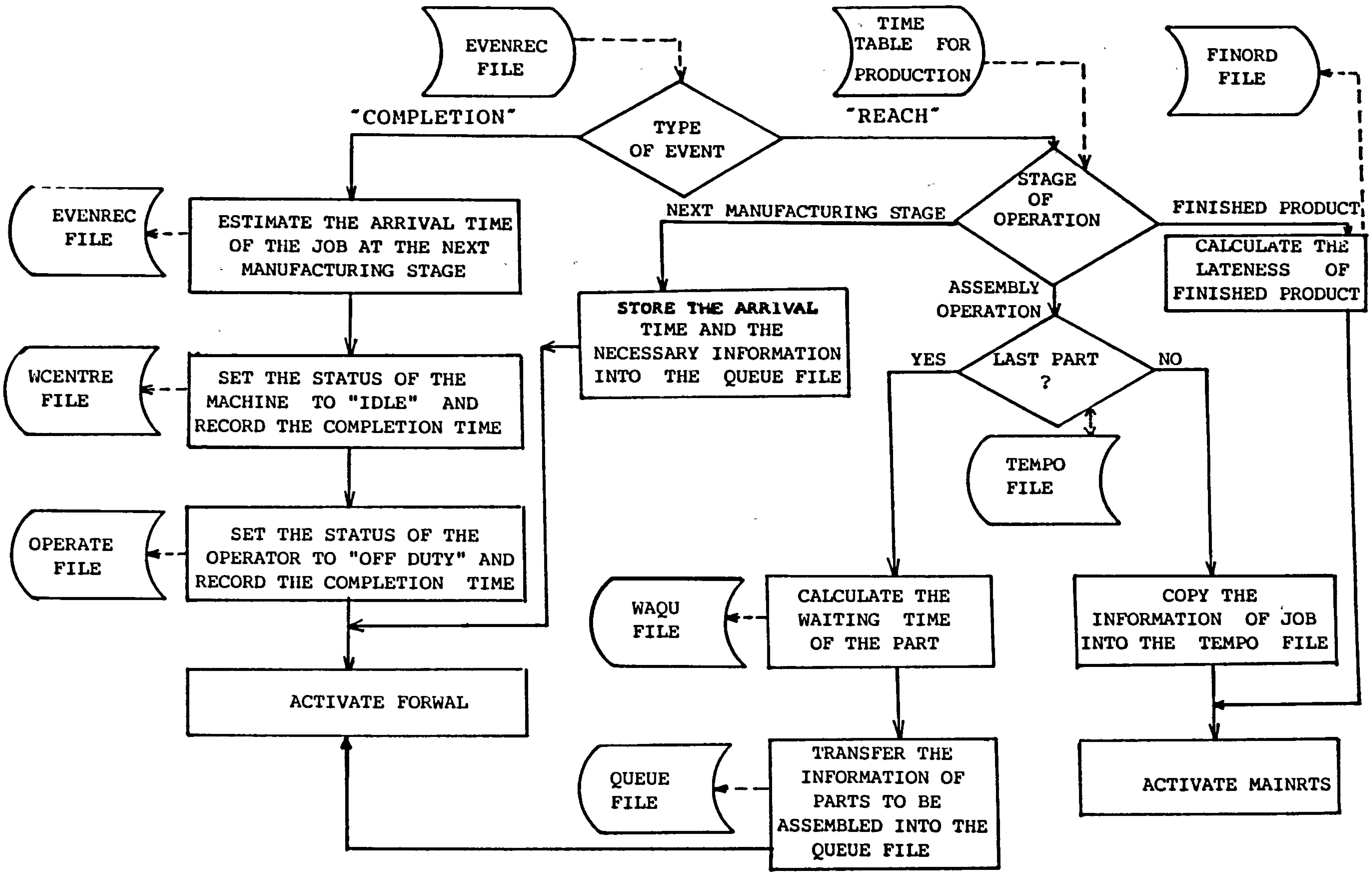


FIG. V.5 : Outline Flow Chart of COMRET

The estimated arrival time of the job plus the necessary information is transferred into the EVENREC file.

Step 2. Set the status of the machine that just finished the job to "idle" and store the completion time to the WCENTRE file.

Step 3. Set the status of the operator who just completed the job to "not duty" and store the completion time to the OPERAT file.

Step 4. Activate the FORWAL sub-program.

<u>The arrival of a job in the queue at a work centre.</u>

As a consequence of this event, COMRET will work as follows:

Step 1. Check the stage of the job just arrived.

In the case where the job arrives at the next manufacturing stage, the arrival time along with the necessary information concerning the job is recorded in the QUEUE file of the corresponding work centre. Afterwards, the execution of the program will continue to Step 2.

In the case of the part arriving at the work centre for an assembly operation, the part could be either the last part of the assembly or not. If the part is not the last part then the arrival time and the other necessary information for this part is transferred into the TEMPO file. The TEMPO file has the function of keeping the record of parts which are waiting for the last part for the assembly operation. An example of TEMPO file is given in Table V.14. Once this task has been carried out, the process would continue to Step 3.

If the part is the last part, then this part along with the waiting parts are eligible to be assembled. Furthermore, the program continues to carry out the following tasks:

- Calculate the waiting time for each part which is waiting for the last part and store the waiting time in the WAQU file.

- Transfer the information concerning parts to be assembled into the QUEUE file.

Once the two above tasks have been carried out, the execution continues to Step 2.

The ASSEMBLE sub-sub-program was developed in order to carry out the task concerning with the arrival of a part at a work centre for an assembly operation.

In the case where a finished product is ready to deliver to the customer, the RESULT sub-sub-program, that was developed in order to support COMRET, would calculate the tardiness of the finished product according to the equation in Chapter IV and store it in the FINORD file (Table V.15). Then the program proceeds to Step 3.

Step 2. Activate the FORWAL sub-program.

Step 3. Activate the MAINRTS.

TABLE V.14 TEMPO FILE

CURRENT TIME : 881631

ARRIV TIME	ORD. No.	PART CODE	QTY.	PRIO RITY	DUE DATE	W/C No.	PARENT CODE	NEXT W/C
881533	0109	A341	26	S	882828	404	M100/1	403
881543	0115	B711	23	S	882926	405	SA800/X	404
881543	0118	B711	22	S	882935	405	SA800/X	404
881544	0133	B721	81	P	883231	407	A3222	405
881546	0118	A342	22	S	882935	404	M200/2	403
881546	0138	B722	34	S	882241	407	A3234	405
881548	0140	B742	28	S	882418	407	A323B	405
881549	0112	A341	24	S	882837	404	M200/1	403
881552	0115	A341	23	S	882926	404	M200/1	403
881552	0121	B711	21	S	883025	405	SA800/X	404
881552	0124	B712	23	S	883035	405	SA800/X	404
881554	0124	A333	23	S	883035	404	M200/3	403
881554	0121	A342	21	S	883025	404	M200/2	403
881555	0127	A333	25	S	883128	404	M100/3	403
881556	0130	A333	26	S	883138	404	M100/3	403
881556	0130	B712	26	S	883138	405	SA800/X	404
881557	0124	A343	23	S	883035	404	M200/3	403
881558	0100	A313	26	S	882638	404	M100/3	403
881559	0143	B721	27	S	882256	407	A3214	405
881559	0127	A343	25	S	883128	404	M100/3	403
881612	0140	B712	28	S	882418	405	SA800/X	404
881613	0136	B721	28	S	883241	407	A3222	405
881614	0130	A343	26	S	883138	404	M100/3	403
881615	0133	B711	27	P	883231	405	SA800/X	404
881621	0146	B742	26	S	882517	407	A323B	405
881621	0136	A332	28	S	883241	404	M100/2	403

DUE DATE = The due date on which the finished product is to be delivered to the customer.

TABLE V.15 FINORD FILE

ORDER No.	ORDER CODE	ORD QTY	ARRIVAL DATE	DUE DATE	COMPL. DATE	TARDY DAYS	WORK CONT hrs	PRIO RITY
0005	A331	33	880428	880454	880514	1	4	S
0006	A341	23	880428	880558	880521	0	9	P
0008	A333	35	880436	880513	880525	1	4	S
0009	A341	20	880436	880522	880527	0	8	S
0011	A331	36	880445	880521	880533	1	4	S
0003	A3214	25	880411	880531	880537	0	33	S
0012	A342	24	880445	880536	880538	0	9	S
0015	A3224	30	880454	880641	880635	0	39	S
0002	A302	16	880411	880633	880644	1	44	S
0018	A3234	34	880515	880737	880718	0	45	S
0014	A303	17	880454	880756	880738	0	47	S
0035	A331	33	880654	880728	880738	1	4	S
0036	A341	23	880654	880748	880748	0	11	P
0038	A333	35	990712	880736	880749	1	4	S
0039	A341	20	880712	880746	880754	0	9	S
0041	A331	36	880719	880745	880756	1	4	S
0020	SA810B/3M	28	880527	880918	880758	0	90	S
0027	A312	12	880553	880854	880813	0	26	S
0042	A342	24	880719	880755	880815	0	10	S
0021	A313	13	880527	880815	880819	0	27	S
0024	A311	14	880541	880816	880822	0	29	S
0030	A3224	29	880616	880935	880823	0	41	S
0023	SA814/1S	27	880541	880854	880823	0	43	S
0017	A302	19	880515	880816	880824	0	51	S
0033	A3214	25	880635	881023	880835	0	36	S
0026	SA810B/3M	26	880553	880957	880838	0	80	S
0029	A301	18	880616	881015	880912	0	47	S
0032	A302	16	880635	881052	880918	0	44	S
0045	A3224	30	880727	881125	880923	0	38	S
0001	M234/2M	21	880411	880957	880929	0	214	S
0048	A3234	34	880739	881134	880938	0	45	S
0004	M212/3M	23	880428	881026	880953	0	172	S
0051	A313	13	880752	881136	880955	0	27	S
0053	SA814/1S	27	880815	881157	881023	0	43	S
0065	A331	33	880927	880955	881023	1	4	S
0066	A341	23	880927	881124	881025	0	9	P
0007	M124/3M	25	880436	881128	881025	0	213	S
0068	A333	35	880936	881113	881032	0	4	S
0044	A303	17	880727	881116	881033	0	47	S
0057	A312	12	880827	881154	881035	0	26	S
0069	A341	20	880936	881125	881035	0	9	S
0054	A311	14	880815	881154	881038	0	29	S
0072	A342	24	880944	881127	881043	0	9	S
0010	M1222/3S	26	880445	881138	881045	0	213	S
0050	SA810B/3M	28	880752	881318	881052	0	88	S
0071	A331	36	880944	881114	881052	0	4	S
0047	A302	19	880739	881121	881054	0	53	S
0013	M132/2M	27	880454	881231	881116	0	241	P

TABLE V.15 FINORD FILE (continued)

ORDER No.	ORDER CODE	ORD QTY	ARRIVAL DATE	DUE DATE	COMPL. DATE	TARDY DAYS	WORK CONT hrs	PRIO RITY
0060	A3224	29	880841	881333	881122	0	41	S
0056	SA810B/3M	26	880827	881357	881132	0	83	S
0063	A3214	25	880858	881423	881134	0	33	S
0016	M112/2S	28	880515	881241	881137	0	192	S
0075	A3224	30	880953	881525	881158	0	38	S
0019	M124/1S	26	880527	881328	881214	0	222	S
0059	A301	18	880841	881315	881215	0	47	S
0078	A3234	34	881014	881532	881225	0	47	S
0022	M224/1S	24	880541	881337	881233	0	216	S
0081	A313	13	881026	881417	881245	0	27	S
0062	A302	16	880858	881355	881247	0	44	S
0025	M214/1M	23	880553	881426	881251	0	172	S
0099	A341	20	881211	881423	881254	0	8	S
0095	A331	33	881153	881331	881258	0	4	S
0096	A341	23	881153	881333	881313	0	10	P

DUE DATE : The due date on which the finished product is to be delivered to the customer.

V.5 ADAPTIVE PROCEDURE

Due to randomness in the production times, it is often found that the actual production time for a job differs from that originally calculated in the time table for production. Consequently, the information in the CAPACITY file would be inaccurate. To overcome this and to enable the program to estimate the promised delivery date of the finished product more realistically, it is necessary to carry out some adjustment to the CAPACITY file and to the LOAD file before new orders are loaded to work centres. The ADAPTIVE sub-program was developed to carry out the adjustment. The outline flow chart of the program is depicted in Fig. V.6. The program works according to the following steps:

Step 1. Adjust the CAPACITY file.

In this step, the program would set the available capacity of each work centre equal to the normal capacity starting from the arrival time of a new order. In order to carry out this process, the ADCAP sub-sub-program was developed.

Step 2. Reload the jobs which have not been performed to the work centres.

Step 3. Activate the INTILOD to load the new orders to the available capacity of work centres.

V.6 DOWN

By means of the program, the effect of a "breakdown" or "ready" event on the production system during the simulation period can be detected. The outline flow

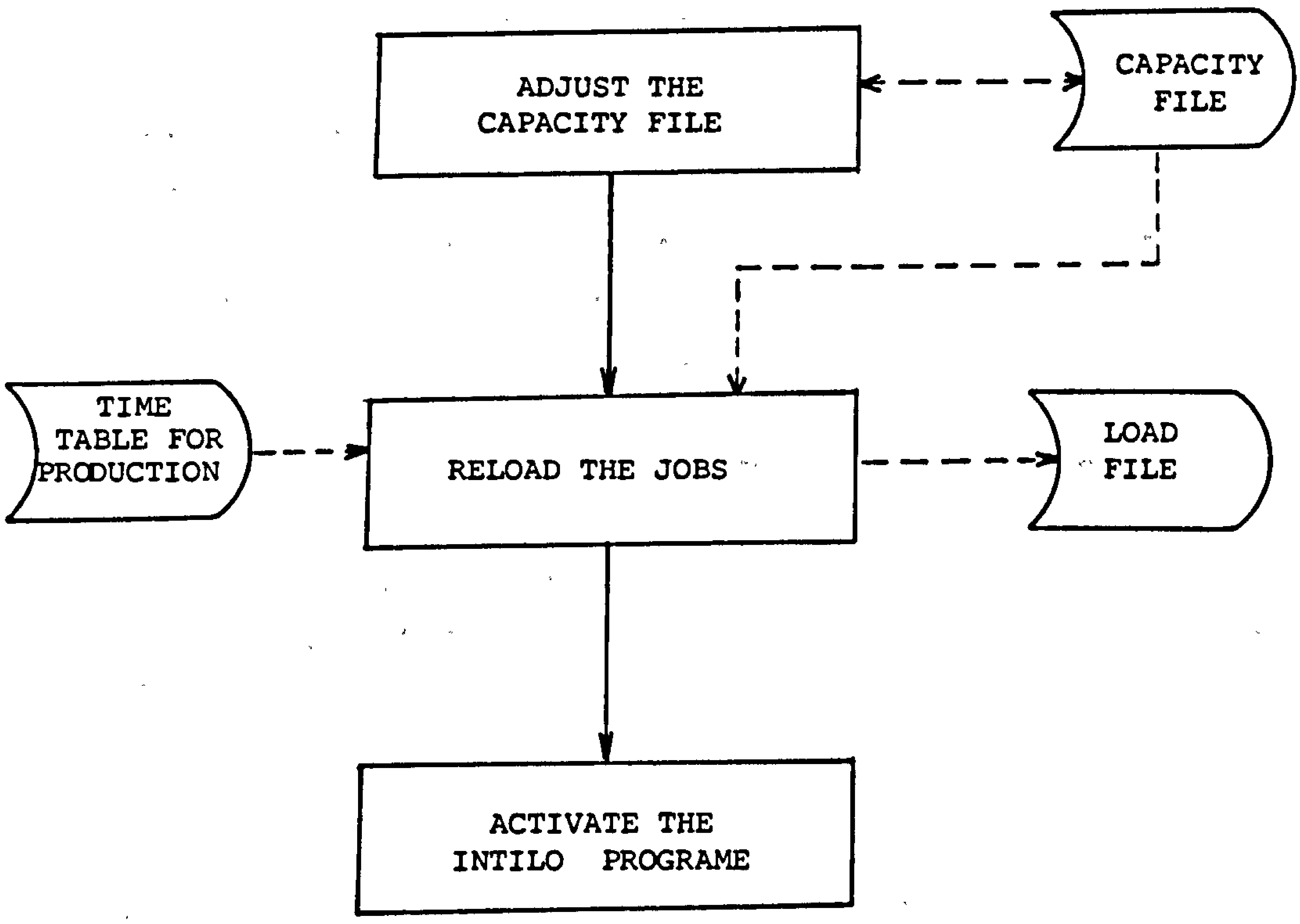


FIG. V.6 : Outline Flow Chart of ADAPTIVE chart of the DOWN program is presented in Fig. V.7. Since the program is activated by a "breakdown" event, it will work as follows.

Step 1. Simulate a machine breakdown.

The program generates a random number, having a value ranging between zero and one, and uses the random number to determine which machine will breakdown with the assumption that each machine has an equal probability of breaking down.

Step 2. Set the status of the machine to "down".

Set the status of the machine which is out of action to "down" by updating the corresponding record in the WCENTRE file.

Step 3. Calculate the machine service time.

Assumes that the machine service time follows a uniform distribution where the minimum and maximum service time of each machine is 4 and 8 hours respectively. The program calculates the machine service time based on the equation:

$$mst = ta + RND \times (tb - ta)$$

where,

mst = the machine service time

ta = the minimum service time

tb = the maximum service time

RND = random number.

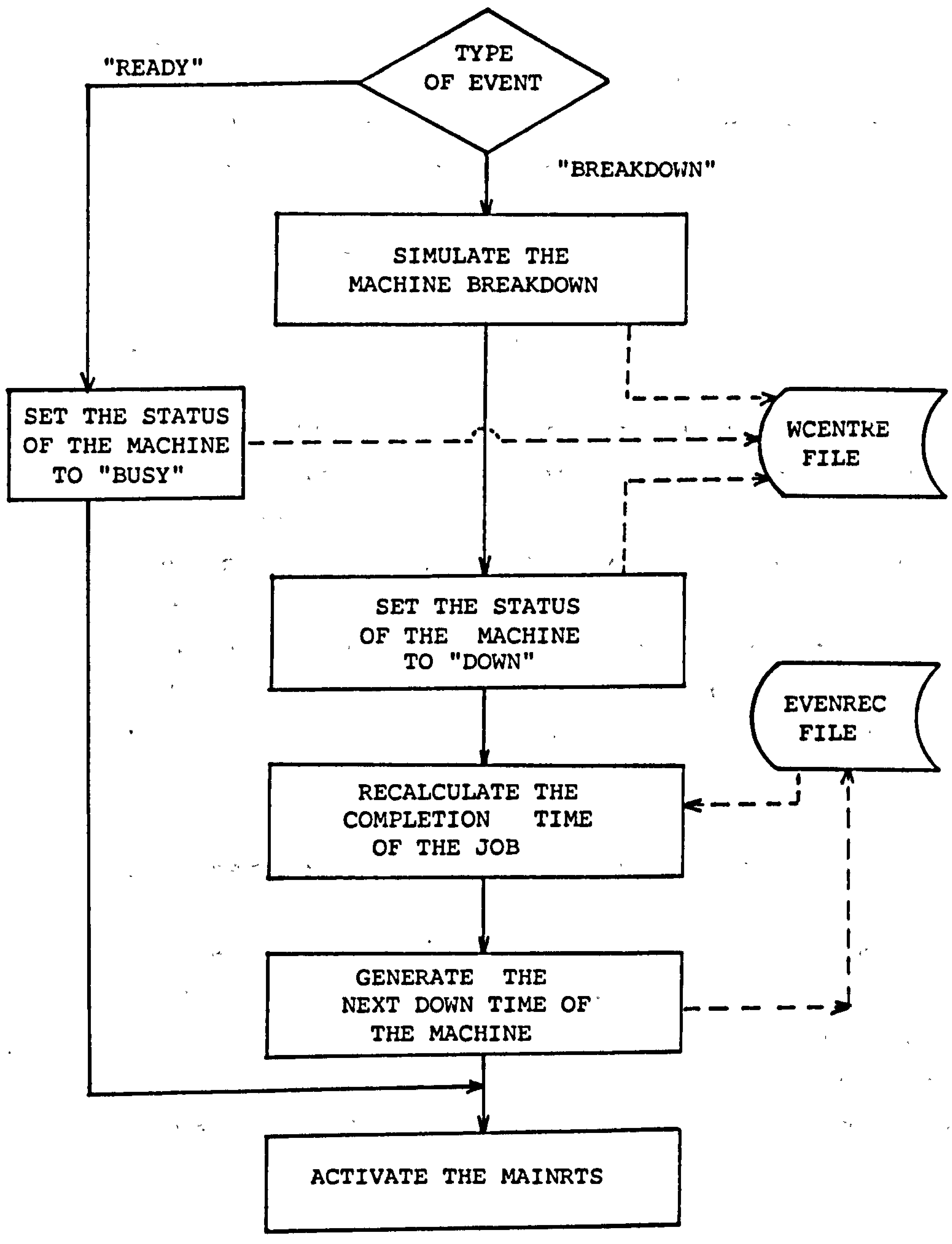


FIG. V.7 : Outline FLow Chart of DOWN

Having calculated the machine service time (mst) the machine proceeds to calculate the time when the machine will be back in service by adding the machine service time to the time when the machine broke down. Thereafter, the result along with the relevant information is transferred into the EVENREC file.

Step 3. Recalculate the completion time of the job.

Subsequently, the completion time for the job, the processing of which has been interrupted, must be extended to include the machine service time. To do this, the program will calculate the new completion time of the job by adding the machine service time to the completion time of the job as calculated previously. The new completion time would be copied into the EVENREC file by replacing the old completion time.

Step 4. Generate the next down time of the machine.

The machines in each work centre will be down from time to time during the simulation period. In developing the system it has been assumed that the down time of the machine follows an exponential distribution with a mean of one week. The program calculates the next down time of the machine by the equation

$$td_2 = td_1 + [- \log_e (1 - RND) \times md]$$

where,

td_2 = the next down time of the machine

td_1 = the previous down time of the machine

md = the average interdown time

RND = the random number.

In the case of the "ready" event the program will change the status of the machine from "down" to "busy" and then activate MAINRTS.

CHAPTER VI

THE ANOVA PROCEDURE APPLIED TO THE ANALYSIS OF OUTPUT

VI.1 Introduction

In order to determine the effect of each strategy or interaction amongst the strategies which were employed during the research, the observations from the simulation runs need clarification through statistical analysis. In relation to the type of research carried out, factorial experiments are the most efficient for this type of analysis. According to Montgomery (58) by a factorial experiment is meant that in each complete trial (run) or replication of the experiment all possible combination of the levels of the factors are investigated. For example, if there are 'a' levels of factor 'A' and 'b' levels of factor 'B', then each replicate contains all ab treatment combinations. When factors are arranged in a factorial experiment they are often said to be "crossed".

The effect of a factor is defined to be the change in response produced by a change in the level of the factor. This is frequently called "a main effect" because it refers to the primary factors of interest in the experiment. For example consider the data in Table VI.1.

Table VI.1 A factorial experiment

A \ B	B_1	B_2
A_1	20	30
A_2	40	52

The main effect of factor "A" could be thought of as being the difference between the average response at the first level of "A" and the average response at the second level of "A". Numerically, this is

$$A = \frac{40 + 52}{2} - \frac{20 + 30}{2} = 21$$

That is, increasing factor "A" from level 1 to level 2 causes an average response increase of 21 units. Similarly, the main effect of factor "B" is

$$B = \frac{30 + 52}{2} - \frac{20 + 40}{2} = 11$$

That is, increasing factor "B" from level 1 to level 2 causes an average response increase of 11 units.

In some experiments, it may be found that the difference in response between the levels of one factor is not the same at all the levels of the other factors. When this occurs, there is an interaction between the factors.

For example, consider the data in Table VI.2

Table VI.2 A Factorial Experiment with Interaction

A \ B	B_1	B_2
A_1	20	40
A_2	50	12

At the first level of factor "B" the "A" effect is

$$A = 50 - 20 = 30$$

and the second level of factor "B" the "A" effect is

$$A = 12 - 40 = -28$$

Since the effect of "A" depends on the level chosen for factor "B", it can be seen there is interaction between "A" and "B".

These ideas may be illustrated graphically. Figure VI.1 plots the response data in Table VI.1 against factor "A" for both levels of factor "B".

Note that the B_1 and B_2 lines are approximately parallel, indicating a lack of interaction between factors A and B. Similarly, Figure VI.2 plots the response data in Table VI.2.

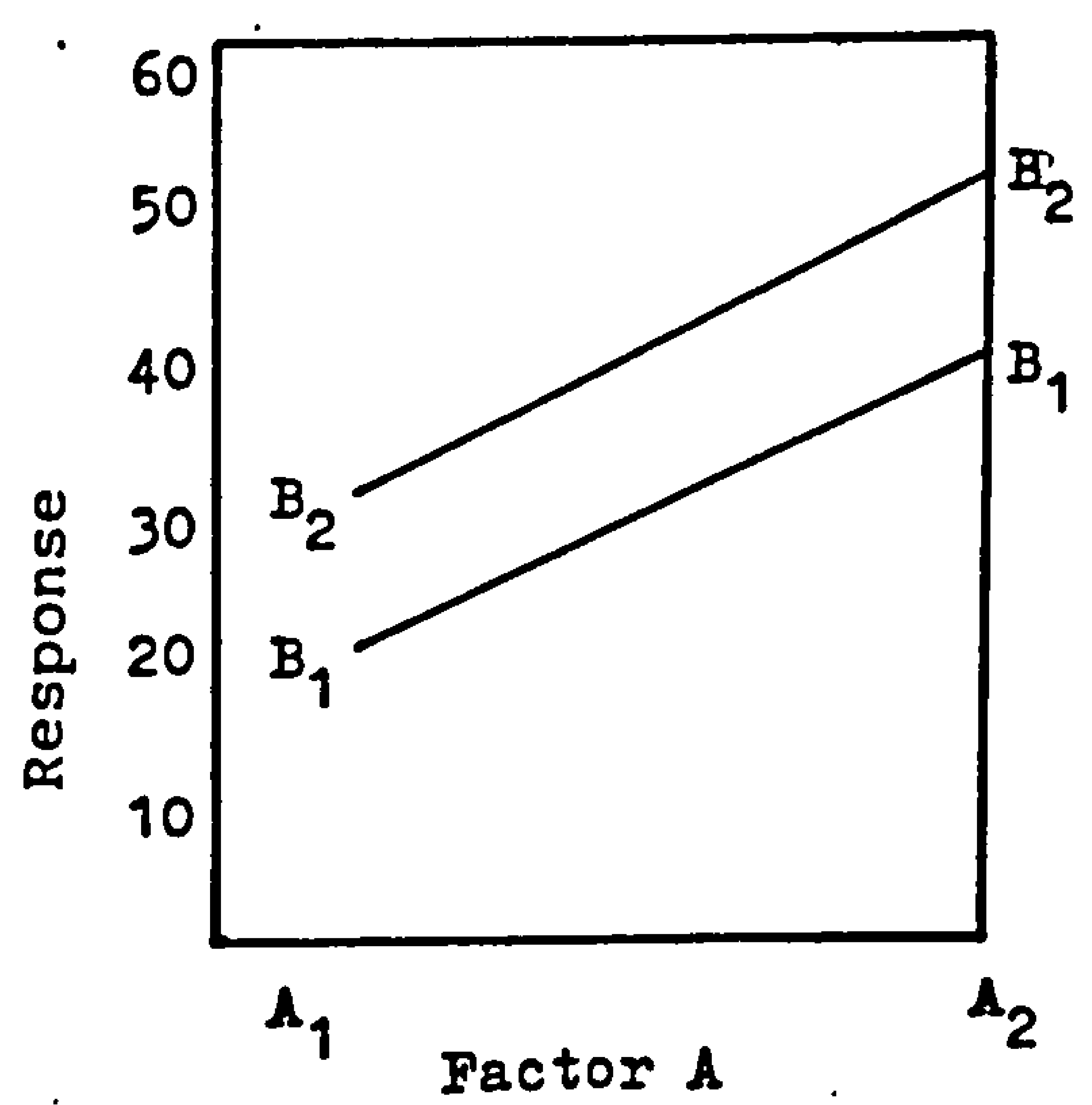


Fig.VI.1. A factorial experiment without interaction

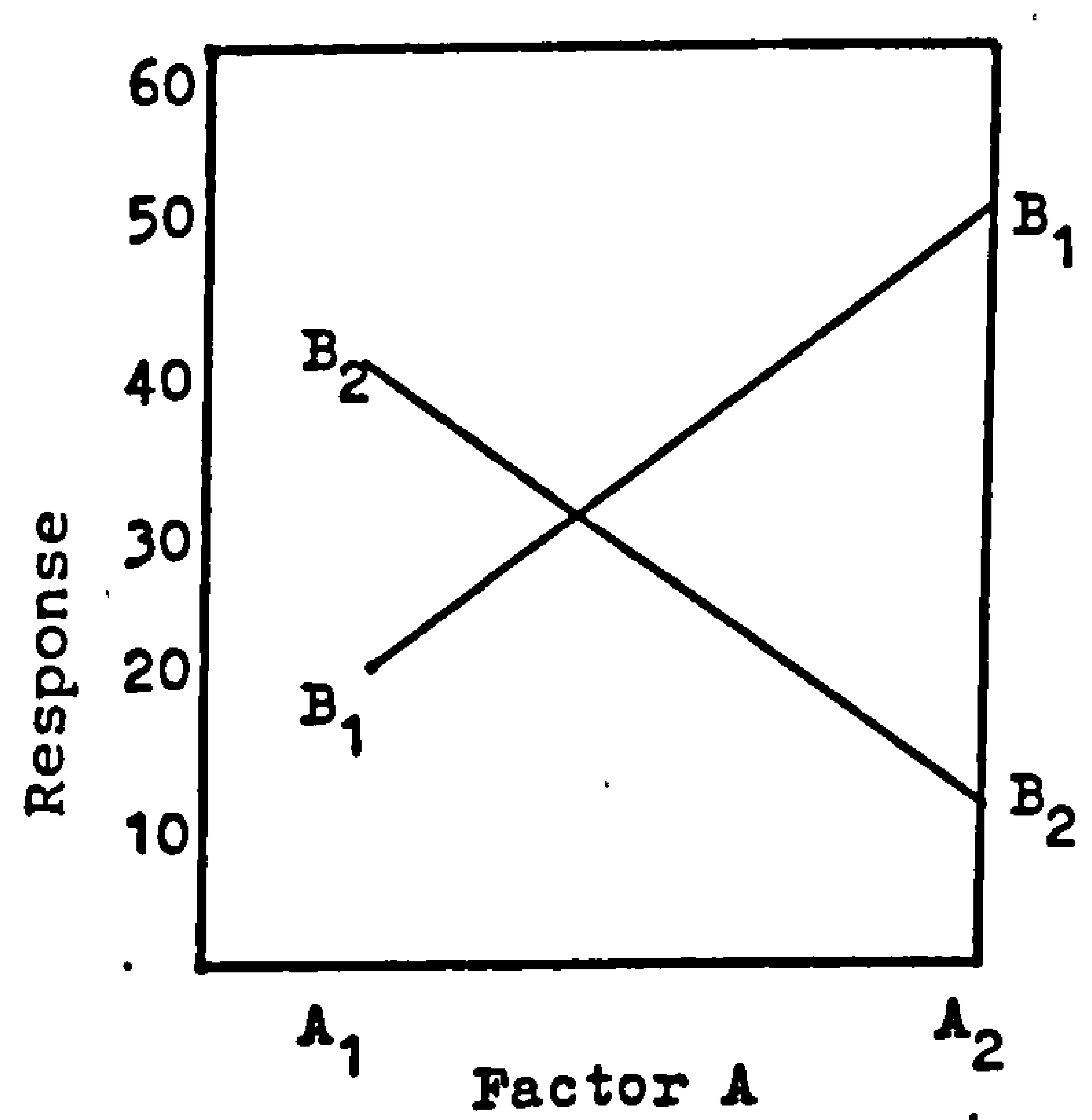


Fig.VI.2. A factorial experiment with interaction

Here it can be seen that the B_1 and B_2 lines are not parallel. This indicates an interaction between factors "A" and "B". Graphs such as these are frequently very useful in interpreting significant interactions and in reporting results to non-statistically trained management.

Note that when an interaction is large, the corresponding main effects have little practical meaning. For the data of Table VI.2, the main effect of factor "A" is

$$A = \frac{50 + 12}{2} - \frac{20 + 40}{2} = 1$$

which is very small, and it can be concluded that there is no effect due to "A". However, when the effects of "A" at different levels of factor "B" are examined, it can be seen this is not the case. Factor "A" has an effect, but it depends on the level of factor "B"; that is, knowledge of the AB interaction is more useful than knowledge of the main effect. A significant interaction can tend to mask the significance of main effects. This is clearly indicated by the data in Table VI.2. In the presence of significant interaction, the experimenter can examine the levels of one factor, say "A", with levels of the other factors fixed to assist in drawing conclusions about the main effect of "A".

VI.2 Experimental Design

As mentioned earlier in Chapter IV, the simulation examines the impact of four factors; the due date assignment method, priority rule, process batch method and operator reassignment method. The priority rule is tested at six levels, while due date assignment method, process batch method and operator reassignment method are tested at two levels each. The factors and factor levels are described below and are summarised in Table VI.3.

The 2 x 6 x 2 x 2 complete factorial experiment tests 48 possible treatment combinations. Each combination is replicated five times for a total of 240 simulation runs. The results of the simulation experiment are statistically analysed by a multifactor analysis of variance (ANOVA) model. The ANOVA procedure determines which of the four factors affects the performance and whether the interaction of the factors produces significant differences in job performance. Post ANOVA analysis to identify where significant differences in performance occur is conducted via Duncan's multiple comparison test.

VI.2.1 The Analysis of Variance (ANOVA)

The type of factorial experiment applied involves four factors. There are 2 levels of factor A (the due date assignment method), 6 levels of factor B (the priority rule), 2 levels of factor C (the process batch method) and 2 levels of factor D (the operator reassignment method) and these are arranged in a factorial design; that is, each replicate of the experiment contains all 2 x 6 x 2 x 2 treatment combinations. There are five replicates of the experiment. Let Y_{ijklm} represent the observation taken under the ith level of factor A, the jth level of factor B, the kth level of factor C, and the lth level of factor D in the mth replicate; then the data arrangement for this type of experiment is as shown in Table VI.4. Meanwhile the observations may be described by the linear statistical model,

TABLE VI.3 2x6x2x2 COMPLETE FACTORIAL EXPERIMENT

FACTOR	FACTOR LEVELS
A = Due date assignment method	a_1 = Total Work Content (TWC) a_2 = Material Requirement Planning (MRP)
B = Priority Rule	b_1 = Critical Ratio (CR) b_2 = First Come First Served (FCFS) b_3 = Shortest Imminent Operation Time (SIOT) b_4 = Earliest Due Date (EDD) b_5 = Slack Time Remaining (STR) b_6 = Slack Time Remaining per Operation (STRO)
C = Process Batch Method	c_1 = Fixed Process Batch (FPB) c_2 = Variable Process Batch (VPB)
D = Operator Reassignment Policy	d_1 = Centralised Operator Reassignment (COR) d_2 = Decentralised Operator Reassignment (DOR)

	a1												a2											
	b1		b2		b3		b4		b5		b6		b1		b2		b3		b4		b5		b6	
	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2	c1	c2
d1	Y11111	Y11211	Y12111	Y12211	Y13111	Y13211	Y14111	Y14211	Y15111	Y15211	Y16111	Y16211	Y21111	..	..	..	..	..	..	..	..	..	..	Y26211
	Y11112	...	...	...	...	...	...	...	...	...	...	Y16212	Y21112	..	..	..	..	..	..	..	..	..	..	Y26212
	Y11113	...	...	...	...	...	...	...	...	...	...	Y16213	Y21113	..	..	..	..	..	..	..	..	..	..	Y26213
	Y1114	...	...	...	...	...	...	...	...	...	...	Y16214	Y21114	..	..	..	..	..	..	..	..	..	..	Y26214
	Y11115	Y11215	Y12115	Y12215	Y13115	Y13215	Y14115	Y14215	Y15115	Y15215	Y16115	Y16215	Y21115	..	..	..	..	..	..	..	..	..	..	Y26215
d2	Y11121	...	...	...	...	...	...	...	...	...	...	Y16221	Y21121	..	..	..	..	..	..	..	..	..	..	Y26221
	Y11122	...	...	...	...	...	...	...	...	...	...	Y16222	Y21122	..	..	..	..	..	..	..	..	..	..	Y26622
	Y11123	...	...	...	...	...	...	...	...	...	...	Y16223	Y21123	..	..	..	..	..	..	..	..	..	..	Y26623
	Y11124	...	...	...	...	...	...	...	...	...	...	Y16224	Y21124	..	..	..	..	..	..	..	..	..	..	Y26624
	Y11125	...	...	...	...	...	...	...	...	...	...	Y16225	Y21125	..	..	..	..	..	..	..	..	..	..	Y26625

Table VI.4. The data arrangement for 2 x 6 x 2 x 2 factorial experiment

$$y_{ijklm} = u + A_i + B_j + C_k + D_l + AB_{ij} + AC_{ik} + AD_{il} + BC_{jk} + BD_{jl} + CD_{kl} + ABC_{ijk} + ABD_{ijl} + BCD_{jkl} + ABCD_{ijkl} + E_{m(ijkl)}$$

where,

y_{ijklm} = represent the observation taken under the ith level of factor A, the jth level of factor B, the kth level of factor C, and the lth level of factor D in the mth replication

$i = 1, \ldots., a \; ; \; a = 2$

$j = 1, \ldots., b \; ; \; b = 6$

$k = 1, \ldots., c \; ; \; c = 2$

$l = 1, \ldots., d \; ; \; d = 2$

$m = 1, \ldots., n \; ; \; n = 5$

e.g. y_{11112} represents the second observation using level 1 of the factor A, level 1 of the factor B, level 1 of the factor C and level 1 of the factor D.

u	=	a common effect for the whole experiment
A_i	=	the effect of the ith level of factor A
B_j	=	the effect of the jth level of factor B
C_k	=	the effect of the kth level of factor C
D_l	=	the effect of the lth level of factor D
AB_{ij}	=	the effect of the interaction between A_i and B_j
AC_{ik}	=	the effect of the interaction between A_i and C_k
AD_{il}	=	the effect of the interaction between A_i and D_l
BC_{jk}	=	the effect of the interaction between B_j and C_k
BD_{jl}	=	the effect of the interaction between B_j and D_l
ABC_{ijk}	=	the effect of the interaction between A_i, B_j and C_k
ABD_{ijl}	=	the effect of the interaction between A_i, B_j and D_l
ACD_{ikl}	=	the effect of the interaction between A_i, C_k and D_l
BCD_{jkl}	=	the effect of the interaction between B_j, C_k and D_l
$ABCD_{ijkl}$	=	the effect of the interaction between A_i, B_j, C_k and D_l
$E_{m(ijkl)}$	=	the effect of the mth experiment with respect to the ijklth treatment.

$E_{m(ijkl)}$ is considered to be a normally and independently distributed random effect whose mean is zero and whose variance is the same for all treatments or levels. This is expressed as: $E_{m(ijkl)}$ are $NID(0,\sigma_e^2)$ where σ_e^2 is the common variance within all treatments.

Based on the equation on page 103, for the ANOVA requirements, it is necessary to calculate the following factors

1. The sum of squares of all observations

$$Y^2 = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} \sum_{m=1}^{n} (Y_{ijklm})^2$$

2. The mean of square of all observations

$$SY = \left[\sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} \sum_{m=1}^{n} Y_{ijklm}\right]^2 / (axbxcxdxn)$$

3. The sum of squares between all treatments A,B,C,and D

$$SSABCD = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} [T_{ijkl}{}^2/n] - SY$$

4. The sum of squares between treatments A,B, and C

$$SSABC = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} [T_{ijk}{}^2/(dxn)] - SY$$

T_{ijk} = the total of the observations involving the ith level of factor A, the jth level of factor B, and the ith level of factor C.

5. The sum of squares between treatments A, B, and D

$$SSABD = \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{l=1}^{d} [T_{ijl}{}^2/(cxn)] - SY$$

6. The sum of squares between treatments A, C, and D

$$\text{SSACD} = \sum_{a=1}^{a} \sum_{k=1}^{c} \sum_{l=1}^{d} [T_{ikl}{}^2/(bxn)] - SY$$

7. The sum of squares between treatments B, C, and D

$$\text{SSBCD} = \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} [T_{jkl}{}^2/(axn)) - SY$$

8. The sum of squares between treatments A and B

$$\text{SAB} = \sum_{i=1}^{a} \sum_{j=1}^{b} [T_{ij}{}^2/(cxdxn)] - SY$$

9. The sum of squares between treatments A and C

$$\text{SAC} = \sum_{i=1}^{a} \sum_{k=1}^{c} [T_{ik}{}^2/(bxdxn)] - SY$$

10. The sum of squares between treatments A and D

$$\text{SAD} = \sum_{i=1}^{a} \sum_{l=1}^{d} [T_{il}{}^2/(bxcxn)] - SY$$

11. The sum of squares between treatments B and C

$$\text{SBC} = \sum_{j=1}^{b} \sum_{k=1}^{c} [T_{jk}{}^2/(axdxn)] - SY$$

12. The sum of squares between treatments B and D

$$SBD = \sum_{j=1}^{b} \sum_{l=1}^{d} [T_{jl}^{2}/(axcxn)] - SY$$

13. The sum of squares between treatments C and D

$$SCD = \sum_{k=1}^{c} \sum_{l=1}^{d} [T_{kl}^{2}/(axbxn)] - SY$$

14. The sum of squares for all levels of factor A

$$Ay = \sum_{i=1}^{a} [A_i^{2}/(bxcxdxn)] - SY$$

where,

A_i = the total of all observations for level i of factor A

$$= \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{l=1}^{d} \sum_{m=1}^{n} Y_{ijklm}$$

15. The sum of squares for all levels of factor B

$$By = \sum_{j=1}^{b} [B_j^{2}/(axcxdxn)] - SY$$

where,

B_j = the total of all observations for level j of factor B

$$= \sum_{i=1}^{a} \sum_{k=1}^{c} \sum_{l=1}^{d} \sum_{m=1}^{n} Y_{ijklm}$$

16. The sum of squares for all levels of factor C

$$Cy = \sum_{k=1}^{c} [C_k{}^2/(axbxdxn)] - SY$$

where,

C_k = the total of all observations for level k of factor C

$$= \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{l=1}^{d} \sum_{m=1}^{n} Y_{ijklm}$$

17. The sum of squares for all levels of factor D

$$Dy = \sum_{l=1}^{d} [D_l{}^2/(axbxcxn)] - SY$$

where,

D_l = the total of all observations for level l of factor D

$$= \sum_{i=1}^{a} \sum_{j=1}^{b} \sum_{k=1}^{c} \sum_{m=1}^{n} Y_{ijklm}$$

18. The sum of squares for interaction between factors A and B.

ABy = SAB - Ay - By

19. The sum of squares for interaction between factors A and C.

ACy = SAC - Ay - Cy

20. The sum of squares for interaction between factors A and D.

ADy = SAD - Ay - Dy

21. The sum of squares for interaction between factors B and C.

BCy = SBC - By - Cy

22. The sum of squares for interaction between factors B and D.

BDy = SBD - By - Dy

23. The sum of squares for interaction between factors C and D.

CDy = SCD - Cy - Dy

24. The sum of squares for interaction between factors A, B, and C.

ABCy = SSABC - Ay - By - Cy - ABy - ACy - BCy

25. The sum of squares for interaction between factors A, B, and D.

$$ABDy = SSADB - Ay - By - Dy - ABy - ADy - BDy$$

26. The sum of squares for interaction between factors A, C, and D.

$$ACDy = SSACD - Ay - Cy - Dy - ACy - ADy - CDy$$

27. The sum of squares for interaction between factors B, C, and D.

$$BCDy = SSBCD - By - Cy - Dy - BCy - BDy - CDy$$

28. The sum of squares for interaction between factors A, B, C, and D.

$$ABCDy = SSABCD - Ay - By - Cy - Dy - ABy - ACy - ADy - BCy - BDy - CDy - ABCy - ABDy - ACDy - BCDy$$

29 The sum of squares due to error.

$$Ey = Y^2 - SY - Ay - By - Cy - Dy - ABy - ACy - ADy - BCy - BDy - CDy - ABCy - ABDy - ACDy - BCDy - ABCDy.$$

The number of degrees of freedom associated with each sum of squares of factor, interaction between factors and error is as shown in Table VI. 5.

Assuming that factors A, B, C, and D are fixed. That is, the factors have specifically chosen where the a levels of factor A, the b levels of factor B, the c levels of factor C, and the d levels of factor D used in the design, and, consequently, the inferences drawn from the analysis of variance are applicable only to the levels of A, B, C, and D actually used.

TABLE VI.5 THE NUMBER OF DEGREES OF FREEDOM ASSOCIATED WITH EACH SUM OF SQUARES

EFFECT	SUM OF SQUARES	DEGREES OF FREEDOM
A	Ay	a-1
B	By	b-1
C	Cy	c-1
D	Dy	d-1
AB interaction	ABy	(a-1)(b-1)
AC interaction	ACy	(a-1)(c-1)
AD interaction	ADy	(a-1)(d-1)
BC interaction	BCy	(b-1)(c-1)
BD interaction	BDy	(b-1)(d-1)
CD interaction	CDy	(c-1)(d-1)
ABC interaction	ABCy	(a-1)(b-1)(c-1)
ABD interaction	ABDy	(a-1)(b-1)(d-1)
ACD interactioN	ACDy	(a-1)(c-1)(d-1)
BCD interaction	BCDy	(b-1)(c-1)(d-1)
ABCD interaction	ABCDy	(a-1)(b-1)(c-1)(d-1)
Error	Ey	ab(n-1)
TOTAL	Y^2-SY	abn-1

Utilising this assumption the mean square of each effect in Table VI.5 can be calculated by dividing the sum of squares with the corresponding degrees of freedom.

The hypotheses that are tested for the model on page 103 are:

H_1 : A_i = 0 (no effect of factor A)

H_2 : B_j = 0 (no effect of factor B)

H_3 : C_k = 0 (no effect of factor C)

H_4 : D_l = 0 (no effect of factor D)

H_5 : AB_{ij} = 0 (no effect of interaction between factors A and B)

H_6 : AC_{ik} = 0 (no effect of interaction between factors A and C)

H_7 : AD_{il} = 0 (no effect of interaction between factors A and D)

H_8 : BC_{jk} = 0 (no effect of interaction between factors B and C)

H_9 : BD_{jl} = 0 (no effect of interaction between factors B and D)

H_{10} : CD_{kl} = 0 (no effect of interaction between factors C and D)

H_{11} : ABCijk = 0 (no effect of interaction between factors A, B, and C)

H_{12} : ABD_{ijl} = 0 (no effect of interaction between factors A, B, and D)

H_{13} : ACD_{ikl} = 0 (no effect of interaction between factors A, C, and D)

H_{14} : BCD_{jkl} = 0 (no effect of interaction between factors B, C, and D)

H_{15} : $ABCD_{ijkl}$ = 0 (no effect of interaction between factors A, B, C, and D).

In order to test all the above hypotheses, it is required to calculate the ratio between the corresponding mean square with mean square error. This ratio will follow an F distribution with appropriate numerator and ab(n-1) denominator degrees of freedom, and the critical region will be located in the upper tail. The test procedure is arranged in an analysis of variance such as shown in Table VI.6.

VI.2.2 Duncan Multiple Range Test

Suppose in conducting an analysis of variance for the fixed effect model that the null hypothesis is rejected. Then, ther are differences between the treatments, but exactly which treatments differ is not specified. In this situation, further comparisons test between groups of treatments means may be useful. Several methods have been introduced to handle such situations. Montgomery (58) pointed out that among the more popular of these method tests are those of Newman, Tukey, and Duncan. Carmer and Swanson (67), in an extensive comparison of these and other test procedures, show that Duncan's test is superior to the Newman test in detecting true differences between pairs of means. For this reason, the Duncan's method, which is usually called the Duncan multiple range test, was applied in the comparison test in the analysis of the output. Hicks (59) describes the steps showing how the Duncan's method works can be described as follows:

TABLE VI.6 THE ANALYSIS OF VARIANCE (ANOVA) TABLE FOR THE FIXED EFFECT MODEL

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM (df)	MEAN SQUARE (MS)	Fo
A	Ay	dfA = a-1	MSA = Ay/dfA	MSA/MS error
B	By	dfB = b-1	MSB = By/dfB	MSB/MS error
C	Cy	dfC = c-1	MSC = Cy/dfC	MSC/MS error
D	Dy	dfD = d-1	MSD = Dy/dfD	MSD/MS error
AB	ABy	dfAB = (a-1)(b-1)	MSAB = ABy/dfAB	MSAB/MS error
AC	ACy	dfAC = (a-1)(c-1)	MSAC = ACy/dfAC	MSAC/MS error
AD	ADy	dfAD = (a-1)(d-1)	MSAD = ADy/dfAD	MSAD/MS error
BC	BCy	dfBC = (b-1)(c-1)	MSBC = BCy/dfBC	MSBC/MS error
BD	BDy	dfBD = (b-1)(d-1)	MSBD = BDy/dfBD	MSBD/MS error
CD	CDy	dfCD = (c-1)(d-1)	MSCD = CDy/dfCD	MSCD/MS error
ABC	ABCy	dfABC = (a-1)(b-1)(c-1)	MSABC = ABCy/dfABC	MSABC/MS error
ABD	ABDy	dfABD = (a-1)(b-1)(d-1)	MSABD = ABDy/dfABD	MSABD/MS error
ACD	ACDy	dfACD = (a-1)(c-1)(d-1)	MSACD = ACDy/dfACD	MSACD/MS error
BCD	BCDy	dfBCD = (b-1)(c-1)(d-1)	MSBCD = BCDy/dfBCD	MSBCD/MS error
ABCD	ABCDY	dfABCD = (a-1)(b-1)(d-1)(c-1)	MSABCD = ABCDy/dfABCD	MSABCD/MS error
ERROR	Ey	dferror = ab(n-1)	MS error = Ey/df error	
TOTAL	Y^2-SY	abn - 1		

Fo = the statistic that can be used to test the equality of treatments effects (the F test)

1. Arrange k means (the treatment means to be tested) in ascending order,

2. Enter the ANOVA table and take the error mean square (MS error) with its degrees of freedom,

3. Obtain the standard error of the means for each treatment.

$$S_{Y_i} = \sqrt{\frac{\text{MS error}}{\text{No. of observations in } Y_i}}$$

4. From Duncan's table of significant ranges (Table E.44) obtain the values $r_\alpha(p,f)$, for p = 2,3,...k, where α is the significant level and f is the number of degrees of freedom for error mean square (MS error), and list these k-1 ranges.

5. Multiply these ranges by Sy_i to form a group of k-1 least significant ranges.

6. Test the observed ranges between means, beginning with largest value versus smallest, which is compared with the least significant range for p = k; then test largest versus second smallest with the least significant range for p = k-1; etc. Continue this for second largest versus smallest, etc., until k(k-1)/2 possible pairs have been tested.

If an observed range is greater than the corresponding least significant range, then it can be concluded that the pair of means in question are significantly different. To prevent contradictions, no difference between a pair of means is considered to be significant if the two means involved fall between two other means that do not differ significantly.

CHAPTER VII

SIMULATION RESULTS AND ANALYSIS

VII.1 Introduction

In this chapter are discussed the results of the simulation runs. The effects of each configuration of policies tested on shop performance during the scheduling process are statistically compared. The results of theis simultion runs are analysed by the analysis of variance (ANOVA) to determine statistically whether the due date assignment method, priority rule, process batch method and operator policy or their interactions significantly affect the performance of the job shop considered in this research.

The ANOVA procedure applied in this analysis is presented in Chapter VI. Further analysis to identify where significant differences in performance occurs is conducted via Duncan's multiple range test (59). The procedure showing how the Duncan,s multiple range test works is described in Chapter VI.

Output data are gathered for each simulation run after 25 orders have been completed when the steady state condition of the job shop was achieved. Furthermore, the simulation ends after an additional 75 orders have left the shop. Tables D.1 - D.6 in Appendix D show the simulation results. Each of these tables represents the performance of the job shop which was considered and analysed during the research.

VII.2 Description of the analysis

The mean tardiness, percent tardy, root mean square (RMS) of tardiness, mean work in progress (WIP), mean machine untilisation and mean operator utilisation for each due date assignment method, priority rule, process batch method and operator policy combination averaged over five simulation runs (tabulated from the output of the simulation runs shown in Tables D1 - D.6, in Appendix D) are presented in Table VII.1.

Referring to this table, mean tardiness of those configuration policies involving the slack time remaining (STR) priority rule performs better when compared with others; the mean tardy ranges from 0.02 days to 0.04 days while percent tardy of orders ranges from 1.60% to 2.40%. The result is probably caused by this STR rule giving the highest priority to a job that has the shortest time remaining to the due date of its finished product in the queue at the work centre where it is waiting to be processed first. Since this factor is considered during the scheduling, there is less chance of an order being tardy. From all configurations tested, those configurations involving first come first served (FCFS) and shortest imminent operation time (SIOT) priority rule were equally the worst performers in terms of mean tardiness and percent tardy with mean tardy ranges from 0.13 days to 0.72 days and percent tardy ranges from 4.00% to 12.27%.

Those results are not surprising because neither of these rules takes into account the time required to complete the finished product or the due date of each order during the scheduling process. Hence, there is a strong possibility than an order will be tardy.

TABLE VII.1 MEAN PERFORMANCE OF SIMULATION RUNS

POLICY	TARDI NESS [DAYS]	PERCENT TARDY	RMS OF TARDY	WORK IN PROGRESS (WIP)	MACH INE UTLN [%]	OPER ATOR UTLN [%]
a1b1c1d1	0.15	3.73	4.53	4.70	69.96	80.54
a1b1c1d2	0.17	4.00	3.84	3.97	74.65	83.47
a1b1c2d1	0.12	6.13	2.60	2.35	79.21	84.72
a1b1c2d2	0.15	6.13	3.12	1.74	78.49	86.96
a1b2c1d1	0.66	10.40	9.84	6.09	73.51	82.68
a1b2c1d2	0.72	12.27	8.39	4.22	74.59	84.10
a1b2c2d1	0.19	7.46	3.40	2.64	78.32	86.90
a1b2c2d2	0.17	6.40	3.18	1.80	79.30	82.43
a1b3c1d1	0.64	10.67	9.12	5.79	72.47	83.40
a1b3c1d2	0.22	5.60	5.00	4.13	73.58	82.41
a1b3c2d1	0.32	6.93	5.22	1.69	78.49	85.69
a1b3c2d2	0.28	7.20	4.77	1.54	77.60	86.30
a1b4c1d1	0.38	8.80	4.99	3.55	74.07	80.78
a1b4c1d2	0.15	4.27	4.16	3.65	74.43	82.98
a1b4c2d1	0.39	7.73	5.86	2.05	79.26	86.70
a1b4c2d2	0.25	6.40	4.24	2.42	78.39	86.52
a1b5c1d1	0.03	1.87	1.72	3.70	75.38	81.26
a1b5c1d2	0.03	1.60	1.68	3.39	74.59	80.52
a1b5c2d1	0.03	1.87	1.60	2.41	78.49	85.99
a1b5c2d2	0.03	1.60	1.60	2.27	79.66	85.81
a1b6c1d1	0.30	7.20	4.97	3.64	74.58	82.94
a1b6c1d2	0.19	6.13	4.24	3.04	76.49	82.68
a1b6c2d1	0.19	5.87	3.41	2.40	79.61	86.06
a1b6c2d2	0.31	8.00	4.39	2.20	78.37	86.74
a2b1c1d1	0.16	4.53	3.38	2.42	74.47	83.59
a2b1c1d2	0.14	3.73	3.64	2.74	77.59	82.49
a2b1c2d1	0.15	5.07	2.84	2.11	79.37	86.77
a2b1c2d2	0.17	7.20	2.49	2.40	79.62	86.08
a2b2c1d1	0.62	12.27	7.31	2.72	75.59	84.72
a2b2c1d2	0.13	6.66	2.74	3.01	77.53	82.26
a2b2c2d1	0.58	12.00	6.76	2.52	78.18	86.48
a2b2c2d2	0.19	7.20	3.57	1.60	79.61	86.74
a2b3c1d1	0.67	10.93	7.94	3.29	75.51	84.62
a2b3c1d2	0.15	5.60	3.22	3.15	76.18	82.84
a2b3c2d1	0.08	4.00	2.08	1.53	78.39	84.28
a2b3c2d2	0.17	6.13	3.50	1.47	79.46	82.82
a2b4c1d1	0.34	7.47	4.74	2.55	75.66	83.39
a2b4c1d2	0.35	8.26	5.53	2.92	77.74	83.11
a2b4c2d1	0.19	5.33	5.09	1.95	78.67	86.46

TABLE VII.1 MEAN PERFORMANCE OF SIMULATION RUNS (continued)

POLICY	TARDINESS [DAYS]	PERCENT TARDY	RMS OF TARDY	WORK IN PROGRESS (WIP)	MACHINE UTLN [%]	OPERATOR UTLN [%]
a2b4c2d2	0.19	6.93	4.16	2.34	78.58	86.65
a2b5c1d1	0.02	1.60	1.40	2.43	83.41	83.30
a2b5c1d2	0.04	2.40	1.85	2.66	77.50	82.83
a2b5c2d1	0.03	2.13	1.32	2.28	78.62	86.52
a2b5c2d2	0.03	2.40	1.33	2.50	79.54	85.48
a2b6c1d1	0.12	5.07	3.31	3.10	71.37	82.65
a2b6c1d2	0.16	5.87	2.96	2.68	76.46	82.87
a2b6c2d1	0.10	5.07	2.43	2.23	79.34	85.55
a2b6c2d2	0.11	5.07	2.96	2.17	78.25	86.11

Note: a1 = TWC b1 = CR b3 = SIOT b5 = STR c1 = FPB
d1 = COR
a2 = MRP b2 = FCFS b4 = EDD b6 = STRO c2 = VPB
d2 = DOR

e.g. a1b1c1d1 = the policy which consists of TWC due date assignment method, CR priority rule, FPB process batch method, and COR operator reassignment policy.

In terms of mean work in progress, there is no dominant factor amongst those tested during the research. From all configurations, the total work content (TWC), first come first served (FCFS), fixed process batch (FPB), centralised operator reassignment (COR) configuration was the worst performer with the mean work in progress being 6.09. On the other hand, the configuration of material requirement planning (MRP), shortest imminent operation time (SIOT), variable process batch (VPB) and decentralised operator reassignment (DOR) was the best performer giving a mean WIP value of 1.47. In addition, the configurations involving the variable process batch method produces a lower mean work in progess compared with others.

The MRP due date assignment method produces a lower mean tardiness than the TWC due date assignment method. Since the MRP method determines the due dates of the finished products by considering not only total work content but, also, expected transit and queue time, this method is more rational and more precise; therefore, by applying this method for determining the due dates of the finished products there is less possibility of the order being tardy.

In respect of mean machine utilisation, each policy involving variable process batch (VPB) produces a higher performance compared with the policy involving fixed process batch (FPB). This is not a surprising result, since because the VPB method involves splitting up the batch of the order into several process batches, there is less chance of a machine being idle.

In terms of mean operator utilisation, there is little difference between any of the combinations.

As mentioned in Chapter IV, the orders that arrive in the job shop are classified into priority ("P") orders and standard ("S") orders by management. Table VII.2 shows the mean number of orders in "P" class tardy with respect to the priority rule employed during the research. Referring to this table; the configurations involving any one of the priority rules which consider the due date of finished products, i.e. critical ratio (CR), earliest due date (EDD), slack time remaining (STR), and slack time remaining per operation (STRO), were the best performers giving mean number of orders tardy value of zero. Further, the configurations involving the shortest imminent operation time (SIOT) were the worst performers giving mean number of orders tardy as 2.

VII.3 Statistical analysis

Typically, tardiness is represented by both mean tardiness and percent of jobs tardy, as shown in Table VII.1. However, a dilemma arises when comparing the policies with low mean tardiness and high percent of tardy, to the policies with higher mean tardiness but lower percent tardy. For example, referring to Table VII.1 this occured when comparing policy $a_1b_1c_2d_2$ with policy $a_1b_1c_1d_2$. In order to solve this problem, the root mean square of tardiness could be calculated and used as the comparison value between any policies in terms of tardiness. The root mean square (RMS) of tardiness can be calculated as follows;

$$RMS = \sqrt{\frac{\sum_{k=1}^{n} \max\ (0, L_k)^2}{NT}}$$

TABLE VII.2 MEAN NUMBER OF ORDERS IN "P" STATUS TARDY BASED ON PRIORITY RULE

POLICY INVOLVING PRIORITY RULE	MEAN NUMBER OF ORDERS IN "P" STATUS TARDY
CR	0
FCFS	1
SIOT	2
EDD	0
STR	0
STRO	0

where,

RMS = the root mean square of tardiness

L_k = the lateness of the kth order

$= c_k - d_k$

c_k = the completion time of finished product of the kth order

d_k = the due date of the finished product of the kth order

NT = the total number of orders tardy

$= \sum_{k=1}^{n} A_k$; n = the number of orders completed

A_k = the number of orders tardy

$$A_k = \begin{cases} 1 \text{ if } L_k > 0 \\ 0 \text{ if } L_k \leqslant 0 \end{cases}$$

The RMS value tends to penalise the policies with a few jobs that are very late more than those with many jobs that are a little late. In other words, the policy which produces the smallest RMS of tardiness compared to the other policies is considered as the best policy in terms of tardiness.

Tables VII.3-8 show the ANOVA results for mean tardiness, percent of tardiness, RMS of tardiness, mean work in progress, mean machine utilisation, and mean operator utilisation respectively. The computer

TABLE VII.3 ANOVA TEST FOR MEAN TARDINESS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	0.136	0.136	6.552
B	5	3.588	0.718	34.488*
C	1	0.458	0.458	21.993*
D	1	0.403	0.403	19.389*
A x B	5	0.148	0.030	1.421
A x C	1	0.010	0.010	0.463
A x D	1	0.022	0.022	1.041
B x C	5	0.617	0.123	5.926*
B x D	5	0.619	0.124	5.949*
C x D	1	0.184	0.184	8.829*
A x B x C	5	0.836	0.167	8.034*
A x B x D	5	0.589	0.118	5.666*
A x C x D	1	0.000	0.000	0.016
B x C x D	5	0.453	0.091	4.356*
A x B x C x D	5	0.102	0.020	0.982
Error	192	3.995	0.021	
TOTAL	239	12.160		

Note:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level

TABLE VII.4 ANOVA TEST FOR PERCENT TARDINESS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	171.70	171.70	52.80*
B	5	2080.96	416.19	127.99*
C	1	9.68	9.68	2.98
D	1	0.43	0.43	0.13
A x B	5	68.47	13.69	4.21*
A x C	1	13.92	13.92	4.28
A x D	1	0.34	0.34	0.10
B x C	5	40.08	8.02	2.46
B x D	5	59.76	11.95	3.68*
C x D	1	0.07	0.07	0.02
A x B x C	5	37.61	7.52	2.31
A x B x D	5	10.98	2.20	0.68
A x C x D	1	0.47	0.47	0.14
B x C x D	5	68.54	13.71	4.22*
A x B x C x D	5	26.50	5.30	1.63
Error	192	624.35	3.25	
TOTAL	239	3213.87		

NOTE:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level

TABLE VII.5 ANOVA TEST FOR ROOT MEAN SQUARE OF TARDINESS

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	36.14	36.14	19.07*
B	5	450.60	90.12	47.56*
C	1	83.01	83.01	43.81*
D	1	42.82	42.82	22.59*
A x B	5	30.52	6.10	3.22*
A x C	1	10.35	10.35	5.46
A x D	1	0.89	0.89	0.47
B x C	5	63.19	12.64	6.67*
B x D	5	61.03	12.21	6.44*
C x D	1	16.69	16.69	8.81*
A x B x C	5	90.14	18.03	9.51*
A x B x D	5	31.61	6.32	3.34*
A x C x D	1	0.23	0.23	0.12
B x C x D	5	53.63	10.73	5.66*
A x B x C x D	5	5.33	1.07	0.56
Error	192	363.83	1.89	
TOTAL	239	1340.01		

NOTE:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level

TABLE VII.6. ANOVA TEST FOR MEAN WORK IN PROGRESS (WIP)

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	28.74	28.74	74.61*
B	5	4.54	0.91	2.36
C	1	113.04	113.04	293.46*
D	1	3.92	3.92	10.17*
A x B	5	6.13	1.23	3.18*
A x C	1	26.00	26.00	67.49*
A x D	1	5.33	5.33	13.82*
B x C	5	24.89	4.98	12.93*
B x D	5	7.88	1.58	4.09*
C x D	1	0.76	0.76	1.98
A x B x C	5	6.21	1.24	3.22*
A x B x D	5	2.00	0.40	1.04
A x C X D	1	1.91	1.91	4.96
B x C x D	5	1.27	0.25	0.66
A x B x C x D	5	2.58	0.52	1.34
Error	192	73.96	0.39	
TOTAL	239	309.16		

NOTE:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level

TABLE VII.7 ANOVA TEST FOR MEAN MACHINE UTILISATION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	127.81	127.81	34.43*
B	5	96.67	19.33	5.21*
C	1	700.89	700.89	188.84*
D	1	41.43	41.43	11.16*
A x B	5	79.35	15.87	4.28*
A x C	1	106.45	106.45	26.68*
A x D	1	3.96	3.96	1.07
B x C	5	89.11	17.82	4.80*
B x D	5	56.64	11.33	3.05
C x D	1	27.65	27.65	7.45*
A x B x C	5	72.86	14.57	3.93*
A x B x D	5	47.28	9.46	2.55
A x C x D	1	1.18	1.18	0.32
B x C x D	5	136.02	27.20	7.33*
A x B x C x D	5	32.11	6.42	1.73
Error	192	712.63	3.71	
TOTAL	239	2332.04		

NOTE:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level.

TABLE VII.8 ANOVA TEST FOR MEAN OPERATOR UTILISATION

SOURCE OF VARIATION	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARES	Fo
Treatments				
A	1	13.15	13.15	5.18
B	5	16.33	3.27	1.29
C	1	563.23	563.23	221.01*
D	1	1.35	1.35	0.53
A x B	5	34.16	6.83	2.69
A x C	1	16.41	16.41	6.47*
A x D	1	10.61	10.61	4.18
B x C	5	59.64	11.93	4.70*
B x D	5	32.62	6.52	2.57
C x D	1	0.90	0.90	0.35
A x B x C	5	31.46	6.29	2.48
A x B x D	5	30.08	6.02	2.37
A x C x D	1	7.97	7.97	3.14
B x C x D	5	15.93	3.19	1.26
A x B x C x D	5	35.87	7.17	2.83
Error	192	487.10	2.54	
TOTAL	239	1356.81		

NOTE:

A = Due date assignment method
B = Priority rules
C = Process batch method
D = Operator reassignment policy
* = Significant at the 0.01 level

program which was used in order to obtain these results was written in Locomotive BASIC 2.

As mentioned in Chapter VI, the values of F_o (the ratio between the mean square of treatment with error mean square) in Tables VII.3-8 will follow an F distribution. Therefore, the proper statistic in order to test all hypotheses regarding the source of variation found in the ANOVA tables is the F statistic (Table D.7). From Table D.7 can be obtained the values of the critical region of the upper tail of F distribution F_{α, v_1, v_2} at the percent significant level α, the degrees of freedom being v_1 and v_2. In order to test all the hypotheses to be tested on the source of variation in Tables VII.3-8, the following values have been obtained from Table D.7.

- $F_{0.01,1,192} = 6.77$; with 1 and 192 degrees of freedom (v_1 and v_2) at the 1 percent significant level ($\alpha = 0.01$), the critical region of the upper tail of the F distribution is $F > 6.77$.

- $F_{0.01,5,192} = 3.11$; with 5 and 192 degrees of freedom (v_1 and v_2) at 1 percent significant level ($\alpha = 0.01$), the critical region of the upper tail of F distribution is $F > 3.11$.

Since $F_{0.01,1,192} = 6.77$ and $F_{0.01,5,192} = 3.11$, Table VII.3 shows that the main effects of the priority rule (factor B), the process batch method (factor C) and operator reassignment policy (factor D) are significant at the 0.01 level for mean tardiness performance. Further, the first order interactions (interaction between two factors of the configurations not involving factor A, the due date assignment method, are also significant at the 0.01 level for the mean tardiness performance. In addition, all the second order interactions (interaction between three factors) between factors tested are significant with the exception of the interaction between factors A, C, and D.

Referring to Table VII.4, the effects of factors A and B are significant in respect of percent tardy performance. For the first order interactions, the interactions of factors A and B, and factors B and D are also significant while the BCD interaction is only significant for the second order interaction in terms of percent tardy performance. Based on the ANOVA test for root mean square (RMS) of tardiness in Table VII.7, it can be concluded that all the main effects of the four factors A, B, C, and D are significant at the 0.01 level in respect of RMS of tardiness. Meanwhile, the interactions involving factor B and interaction between factors C and D are also significant at the 0.01 level for the RMS of tardiness. All the second order order interactions are significant at this level except the interaction between factors A, C, and D.

In terms of mean work in progress (WIP), the ANOVA test in Table VII.6 shows that all the main effects of the factors are highly significant at the 0.01 level with the exception of the main effect of factor B. For the first order interactions, all these interactions are significant with exception of the interaction between factors C and D. Further, for the second order interaction, the interaction between factors A, B, and C is the only one which is significant at the 0.01 level for this performance.

Table VII.7 shows that all the main effects of the factors are significant at the 0.01 level for mean machine utilisation. Further, for the first order interaction, the interactions involving factor C and the interaction between factors A and B are also significant. For the second order, the interactions which include ABC and BCD are significant at the 0.01 level.

In respect of the mean operator utilisation, Table VII.8 shows that the main effect of factor C is the only significant effect at the 0.01 level. For the first order, the interactions of factors A and C, and factors B and C are also significant.

VII.4 THE MULTIPLE COMPARISON TEST ON THE MEANS OF TREATMENTS

The analysis of variance carried out in Section VII.3 shows that some main effects of factors as well as the effect of interaction of factors are significant on the performance measures considered in this research. In other words, some of the null hypotheses are rejected. Thus, there are differences between some treatments, but exactly which treatments differ is not specified. In this situation, further tests between groups of treatments were carried out. The Duncan's multiple range test (Chapter IV) was employed in order to carry out the test. Furthermore, a computer program written in Locomotive BASIC 2 was developed to support the test.

Based upon the discussions in Sections VII.2 and VII.3, the comparison test was only carried out on the performance measures mean RMS of tardiness, mean work in progress (WIP), mean machine utilisation and mean operator utilisation. Since the four factors tested have been assumed fixed, then it is possible to make comparisons between the individual means of either factors. However, because the interaction between the factors is also significant, then the comparison between the means of a factor (e.g. factor A) may be obscured by the AB interaction. Therefore, the comparison test was only carried out on the means of interactions which are significant according to the ANOVA analysis.

The comparison test of means of each interaction which is significant according to the ANOVA analysis is presented in Appendix E. Further, the results of the comparison test were discussed and during the discussion each significant interaction was presented graphically. The discussion is presented in Appendix E. Table VII.9 shows the summary of the results of the comparison test.

TABLE VII.9 SUMMARY OF RESULTS OF THE COMPARISON TEST ON THE MEANS OF TREATMENTS

PERFORMANCE	INTER ACTION OF FACTORS	THE BEST PERFORMER COMBINATION	THE WORST PERFORMER COMBINATION	REFERENCE GRAPH OF INTER ACTION	FOR TEST THE SIGN. TEST
1.ROOT MEAN	AB	$a_2b_5;a_1b_5$	$a_1b_3;a_1b_2$	Fig.E.1	Table E.3
SQUARE OF	BC	$b_5c_2;b_5c_1$	$b_2c_1;b_3c_1$	Fig.E.2	Table E.5
TARDI-NESS	BD	$b_5d_1;b_5d_2$	$b_3d_1;b_2d_1$	Fig.E.3	Table E.7
	CD	$c_2d_2;c_2d_1;$ c_1d_2	c_1d_1	Fig.E.4	Table E.9
	ABC	$a_2b_5c_2;$ $a_1b_5c_2;$ $a_2b_5c_1;$ $a_1b_5c_1;$ $a_2b_1c_2$	$a_1b_3c_1;$ $a_1b_2c_1$	Fig.E.5 and Fig.E.6	Table E.11
	ABD	$a_2b_5d_1;$ $a_2b_5d_2;$ $a_1b_5d_2;$ $a_1b_5d_1$	$a_1b_2d_1;$ $a_2b_2d_1;$ $a_1b_3d_1;$	Fig.E.7 and Fig.E.8	Table E.13
	BCD	$b_5c_2d_1;$ $b_5c_2d_2;$ $b_5c_1d_1;$ $b_5c_1d_2;$ $b_1c_2d_1;$ $b_1c_2d_2$	$b_2c_1d_1;$ $b_3c_1d_1$	Fig.E.9 and Fig.E.10	Table E.15

TABLE VII.9 SUMMARY OF RESULTS OF THE COMPARISON TEST ON THE MEANS OF TREATMENTS (continued)

PERFORMANCE	INTERACTION OF FACTORS	THE BEST PERFORMER COMBINATION	THE WORST PERFORMER COMBINATION	REFERENCE GRAPH OF INTERACTION	FOR TEST THE SIGN. TEST
2.WORK IN PROGRESS	AB	THE REST	$a_1b_4;a_1b_5;a_1b_3$	Fig.E.11	Table E.17
	AC	$a_2c_2;a_1c_2$	$a_1c_1;a_2c_1$	Fig.E.12	Table E.19
	AD	$a_2d_1;a_2d_2$	$a_1d_2;a_1d_1$	Fig.E.13	Table E.21
	BC	b_3c_2	$b_2c_1;b_3c_1$	Fig.E.14	Table E.23
	BD	THE REST	$b_3d_1;b_2d_1$	Fig.E.15	Table E.25
	ABC	$a_2b_3c_2;a_1b_3c_2;a_1b_1c_2;a_2b_2c_2$	$a_1b_3c_1;a_1b_2c_1$	Fig.E.16 and Fig.E.17	Table E.27

TABLE VII.9 SUMMARY OF RESULTS OF THE COMPARISON TEST ON THE MEANS OF TREATMENTS (continued)

PERFORMANCE	INTER ACTION OF FACTORS	THE BEST PERFORMER COMBINATION	THE WORST PERFORMER COMBINATION	REFERENCE GRAPH OF INTER ACTION	FOR TEST THE SIGN. TEST
3. MACHINE UTILISATION	AB	a_2b_5	a_1b_3;a_1b_1; a_1b_2;a_2b_6; a_1b_4	Fig.E.18	Table E.29
	AC	a_1c_2;a_2c_2	a_1c_1;a_2c_1	Fig.E.19	Table E.31
	BC	THE COMBINATIONS INVOLVING c_2	b_1c_1;b_3c_1 b_6c_1;b_2c_1 b_4c_1	Fig.E.20	Table E.33
	CD	c_2d_1;c_2d_2	c_1d_1;c_1d_2	Fig.E.21	Table E.35
	ABC	THE COMBINATIONS INVOLVING c_2 ;$a_2b_5c_1$	$a_1b_1c_1$; $a_1b_3c_1$; $a_2b_6c_1$; $a_1b_2c_1$	Fig.E.22 and Fig.E.23	Table E.37
	BCD	THE COMBINATIONS INVOLVING c_2 ;$b_5c_1d_1$	$b_1c_1d_1$; $b_6c_1d_1$ $b_3c_1d_1$	Fig.E.24 and Fig.E.25	Table E.39
4. OPERATOR UTILISATION	AC	a_2c_2;a_1c_2	a_1c_1;a_2c_1	Fig.E.26	Table E.41
	BC	THE COMBINATIONS INVOLVING c_2	THE COMBINATIONS INVOLVING c_1	Fig.E.27	Table E.43

TABLE VII.9 SUMMARY OF RESULTS OF THE COMPARISON TEST ON THE MEANS OF TREATMENTS (continued)

NOTES:

A	=	the due date assignment method
a_1	=	TWC
a_2	=	MRP
B	=	the priority rules
b_1	=	CR
b_2	=	FCFS
b_3	=	SIOT
b_4	=	EDD
b_5	=	STR
b_6	=	STRO
C	=	process batch method
c_1	=	FPB
c_2	=	VPB
D	=	operator reassignment policy
d_1	=	COR
d_2	=	DOR

CHAPTER VIII

SUMMARY AND CONCLUSIONS

In this report, the effect of the due date assignment method, priority rule, process batch method, and operator reassignment policy on the performance of the production system which was simulated during the research into real time scheduling has been investigated and evaluated. A simulation model of a hypothetical assembly job shop, written in DBASE III PLUS and called "REALTIS", was used to generate the data for analysis. A multi-factor ANOVA model was designed to assess the impact of the four factors mentioned above on the performance measures which are considered in this research. Based upon the results of the ANOVA analysis, the following conclusions can be drawn:

1. The relative impact of the due date assignment method, priority rule, process batch method, and operator reassignment policy for scheduling policies in real time scheduling was found to be dependent upon the measure of performance considered.

2. In respect of root mean square of tardiness

   a) The due date assignment method, priority rule, process batch method, and operator reassignment policy affect the tardiness of jobs completed by the assembly shop

   b) All the first order interactions involving the priority rules have an effect on performance. Thus, the selection of a due date assignment method, or process batch method, or operator reassignment policy should be influenced by the method in which the priority rules are chosen

c) The method by which the due date of the finished products is assigned does not affect the selection of the process batch method or operator reassignment policy.

3. In respect of work in progress

a) All the factors considered affect the work in progress which builds up during the simulation period, except the priority rule. In other words, the way in which the priority rule operates does not affect performance However, for the first order interactions (interaction between two factors) involving the priority rules have an effect on performance. Thus, the selection of a due date assignment, or a process batch method, or an operator reassignment policy should be influenced by the way in which the priority rule operates. The first order interactions involving the due date assignment method also affect the work in progress. Therefore, the selection of a priority rule, or a process batch method, or operator reassignment method should be influenced by the method in which the due date of the finished products is assigned.

b) The method by which the process batch is applied does not affect the selection of the operator reassignment policy.

4. In respect of machine utilisation

a) All the factors considered affect utilisation of the machines which exist in the simulated assembly shop.

b) All the two factors interaction (the first order interactions) involving process batch method were found to have an effect on performance. In other words, the selection of a due date assignment method or a priority rule, or an operator reassignment policy would be influenced by the process batch method.

c) The operator reassignment policy does not affect the selection of a due date assignment method or a priority rule.

d) The selection of the due date assignment method is affected by the way in which the priority rule operates.

5. In respect of operator utilisation

From all factors tested, the main effect of the process batch method is only on performance. Meanwhile, all the two-factors interaction were found to have no effect on performance, except for the following interactions,

- interaction between the due date assignment method and the process batch method,

- interaction between the priority rule and the process batch method.

Practical Guidelines for using the Policy

The more detailed analysis of output from the experiments (the multiple comparison test of means of performance) in Chapter VII provided practical guidelines. This could be used by the management of an assembly job shop to select an appropriate scheduling policy in attempting to achieve their particular objective, i.e., to meet the promised delivery date of finished products, in applying the real time scheduling system. The guidelines can be specified with respect to the performance measure.

1. In respect of root mean square of tardiness.

   a) The scheduling policies involving the slack time remaining (STR) priority rule should be employed in order to minimise the tardiness of customer orders produced by the company. This policy produces consistently the best results (the least minimum of RMS of tardiness) regardless of the due date assignment method or process batch method or operator reassignment policy employed. The critical ratio (CR) priority rule also performed well in combination with the MRP due date assignment method and the variable process batch (VPB) method. In addition the first come first served (FCFS) rule performed well in combination with the MRP due date assignment method and the DOR operator policy.

   b) Several scheduling policies should be avoided by management. For instance, most of the combinations involving the FCFS rule or SIOT rule perform poorly (maximising the RMS of tardiness). The scheduling policies which should be avoided with respect to this performance are FCFS/FPB, SIOT/FPB, FCFS/COR, SIOT/COR, FPB/COR, TWC/FCFS and TWC/SIOT.

2. In respect of work in progress

   a) The results of this research show that there is no dominant level of due date assignment method in respect to minimising the work in progress.

However, some combinations do not perform as well as others and should be avoided for scheduling assembled products. These are TWC/EDD, TWC/STR, TWC/SIOT, TWC/FPB, MRP/FPB, TWC/COR and TWC/DOR.

b) Beware of the interaction between the priority rule and the process batch method, SIOT/VPB consistently minimised work in progress, but the SIOT/FPB combination produced higher work in progress than did other combinations. In addition, FCFS/FPB gave the worst performance.

c) Scheduling policies based on the operator reassignment policy, such as TWC/COR, TWC/DOR, SIOT/COR, and FCFS/COR, should not be employed.

3. In respect of machine utilisation

a) The combinations involving the VPB are the most important of the process batch methods tested in maximising the utilisation of machines existing in the production system investigated.

b) For the interaction between the due date assignment method and the priority rule, the MRP/STR scheduling policy gave a better performance than other policies. In connection with this interaction the combination TWC/SIOT, TWC/CR, TWC/FCFS, MRP/STRO, and TWC/EDD should not be employed.

c) In respect of the class of operator reassignment policy, there is no dominant policy in terms of machine utilisation performance. However, the combinations involving any of the operator reassignment policy and TWC due date assignment method should not be used.

d) In connection with interaction between the priority rule and the process batch method, all the combinations involving the two factors can be applied in maximising machine-utilisation performance except the combination of the STR priority rule and the FPB process batch method.

4. In respect of operator utilistaion

The combinations involving the variable process batch (VPB) method produced a higher operator utilisation compared with the other combinations.

Table VIII.1 shows the summary of scheduling policies discussed in this section and Table VIII.2 shows the range of tardiness of orders with respect to the priority rule employed during the research.

TABLE VIII.2 RANGE OF TARDINESS OF ORDERS BASED ON PRIORITY RULE

POLICY INVOLVING PRIORITY RULE	RANGE OF TARDINESS [days]
CR	0 - 8
FCFS	0 - 18
SIOT	0 - 16
EDD	0 - 15
STR	0 - 3
STRO	0 - 11

TABLE VIII.1 THE SUMMARY OF SCHEDULING POLICIES FOR PRACTICAL GUIDELINES

PERFORMANCE	INTERACTION OF FACTORS	THE BEST PERFORMER	THE WORST PERFORMER
1 ROOT MEAN SQUARE OF TARDINESS	A and B	MRP/STR; TWC/STR	TWC/SIOT; TWC/FCFS
	B and C	MRP/VPB; MRP/FPB	FCFS/FPB; SIOT/FPB
	B and D	STR/COR; STR/DOR	FCFS/COR; SIOT/COR
	C and D	VPB/DOR; VPB/COR; FPB/DOR	FPB/COR
	A and B and C	MRP/STR/VPB; TWC/STR/VPB; MRP/STR/FPB; TWC/STR/FPB; MRP/CR/VPB	TWC/SIOT/FPB; TWC/FCFS/FPB;
	A and B and D	MRP/STR/COR; MRP/STR/DOR; TWC/STR/DOR; TWC/STR/COR	TWC/FCFS/COR; MRP/FCFS/COR; TWC/SIOT/COR
	B and C and D	STR/VPB/COR; STR/VPB/DOR; STR/FPB/COR; STR/FPB/DOR; CR/VPB/COR; CR/VPB/DOR	FCFS/FPB/COR; SIOT/FPB/COR

TABLE VIII.1 THE SUMMARY OF SCHEDULING POLICIES FOR PRACTICAL GUIDELINES (continued)

PERFORMANCE	INTERACTION OF FACTORS	THE BEST PERFORMER	THE WORST PERFORMER
2. WORK IN PROGRESS	A and B	All except the noted worst performers	TWC/EDD; TWC/STR; TWC/SIOT
	A and C	MRP/VPB; TWC/VPB	TWC/FPB; MRP/FPB
	A and D	MRP/COR; MRP/DOR	TWC/DOR; TWC/COR
	B and C	SIOT/VPB	FCFS/FPB; SIOT/FPB
	B and D	All except the noted worst performers	SIOT/COR; FCFS/COR
	A and B and C	MRP/SIOT/VPB; TWC/SIOT/VPB; TWC/CR/VPB; MRP/FCFS/VPB	TWC/SIOT/FPB; TWC/FCFS/FPB
3. MACHINE UTILISATION	A and B	MRP/STR	TWC/SIOT; TWC/CR; TWC/FCFS; MRP/STRO; TWC/EDD
	A and C	TWC/VPB; MRP/VPB	TWC/FPB; MRP/FPB

TABLE VIII.1 THE SUMMARY OF SCHEDULING POLICIES FOR PRACTICAL GUIDELINES (continued)

PERFORMANCE	INTERACTION OF FACTORS	THE BEST PERFORMER	THE WORST PERFORMER
	B and C	The combinations involving VPB	CR/FPB; SIOT/FPB; STRO/FPB; FCFS/FPB EDD/FPB
	C and D	VPB/COR; VPB/DOR	FPB/COR; FPB/DOR
	A and B and C	The combinations involving VPB; MRP/STR/FPB	TWC/CR/FPB; TWC/SIOT/FPB; MRP/STRO/FPB; TWC/FCFS/FPB
	B and C and D	The combinations involving VPB; STR/FPB/COR	CR/FPB/COR; STRO/FPB/COR; SIOT/FPB/COR
4. OPERATOR UTILISATION	A and C	TWC/VPB; MRP/VPB	TWC/FPB; MRP/VPB
	B and C	The combinations involving VPB	The combinations involving FPB

Reconciliation with the Collateral Research

The experiment performed in this research included more extensive scheduling policies rather than that had been considered in the previous studies. Arguments supporting this idea are,

1. In most research work of this nature, all orders coming to a job shop are considered as being equally important. This is not necessarily realistic, because it is justified by theoretical convenience more than by practical reasons. On the other hand, this research classified the orders coming to the job shop into "priority" orders and "standard" orders. Therefore, jobs which are ready for operation in a particular work centre would be sorted into priority sequence not solely based on priority index but also by considering the class of orders. The same classification concerning the orders have been included by the previous researchers, Galgut (4), Jarvis (5) and Tamkin (6), into real time scheduling and they only used the critical ratio rule for determining the priorities of each job to be scheduled.

2. Previous research reported in the production scheduling literature has been concerned largely with investigating the effects of due date assignment method, priority rules and operator policy. According to the writer's knowledge, there is no mention of the effect of process batch method in production scheduling problem.

   The comparison of the results of this research with the existing body of scheduling literature can be described as follows.

   1. The superior performance of the slack time remaining (STR) priority rule in terms of order tardiness is

consistent with previous researches by Berry (62), Bulkin (63), and Putnam(61).

2. In the context of due date assignment method, a strong interaction between the due date assignment method and priority rules in terms of order tardiness reported by Baker and Bertrand (64), Elvers (47) and Weeks and Fryer (65) is reinforced.

3. The superiority of the centralised operator reassignment (COR) policy to the decentralised operator reassignment (DOR) policy in terms of order tardiness is not consistent with previous research by Weeks and Fryer(65).

4. The results of this research show that the shortest imminent operation time (SIOT) priority rule, which has generally been reported by Conway (42) as being superior in the non assembly environment for tardiness and work in progress measures is not as effective in an assembly environment.

The Future Work

The evaluation of scheduling policies in a real time scheduling system in an assembly shop is a part of developing and implementing of the system in order to achieve a successful operation in a company. Therefore, the results of this research, in general, are not immediately applicable to real job shop scheduling problems. Many other areas for future research need to be conducted in evaluating the performance of various scheduling policies in job shop system. The following problems are suggested for further investigation.

1. The effect of set up time in scheduling policies on the

performance of assembly shop would provide a valuable contribution to the body of research in this area.

2. The impact of altering the product structure in the real time scheduling system is another area open for further investigation.

3. In applying the variable process batch (VPB) method during the research, the size of the process batch was intuitively determined rather than using any optimisation techniques. In relation to this, it is necessary to investigate the effect of various lot-sizing techniques on the performance of assembly shop environments.

4. The impact of order cancellation also needs to be investigated. Since the effect of this variable has not been studied, it is only possible to speculate concerning its influence on the system performance.

The research has led to conjectures which can be assigned a high credibility, at least as an approximation, and which are plainly relevant to the design of the operating of real time scheduling. Also, the study exemplified a general approach of potential practical value. Instead of a theoretical model the simulator developed (REALTIS system) can be made to represent an actual assembly job shop, and simulation should help reveal characteristics of the production system for which a scheduling policy is appropriate or most advantageous on a certain performance. This method does not guarantee an optimum but promises to provide a step in the right direction.

Furthermore, since the system is written in DBASE III PLUS, it can be installed on most micro computers. In recent years, microcomputers have provided opportunities for small businesses to acquire computing power and capabilities hitherto reserved for the larger companies. For many years, micro computers had such limitations as low computational speed, small memory and disk capabilities, and lack of applications software. However, these limitations are being reduced at a rapid rate. These days, most of the new micro computers have larger memories and disk capacities than previous models. The system has been designed and developed on an IBM PC AT.

Finally, the REALTIS consists of a set of different event oriented modules in which each event/activity which occurs during the simulation can be independently controlled. Therefore, separate modules can be linked to operate as a complete system. This feature allows the user to write his own modules (if required) and add them to the system or to ignore the unnecessary modules.

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APPENDIX A

INFORMATION ON SOME SIMULATION STUDIES IN JOB SHOP

In this Appendix is presented some information on simulation studies that have been carried out in job shop scheduling by several researchers. This information includes:

a) arrival pattern, processing and set up time distribution;

b) number of machines, type of shop, due dates assignment method;

c) performance criteria considered;

d) type of investigated.

Definition of some priority rules investigated are,

- FCFS = first come first served
- SIOT = shortest imminent operation time
- STR = slack time remaining
- EDD = earliest due date
- STRO = slack time per remaining operation.

1. Adam and Surkis (68)
   a) Truncated exponential interarrival and processing time.
   b) 6 work centres, job shop.

c) Average flow time, percent of tardy jobs, average tardiness, average earliness.

d) Investigates effects of priority updating procedures and intervals for slack per remaining operation rule.

2. Ashour and Vaswani (69)

a) Poisson and Erlang arrivals, exponential and Erlang processing times.

b) 9 machine pure job shop. Number of operations due dates.

c) Average flow time, average number of jobs in the shop, average lateness, number of tardy jobs, shop utilisation.

d) Compares FCFS, SIOT, STR, EDD, STRO. Investigates effects of changing due dates and variation of processing times.

3. Conway (57)

a) Exponential interarrival times, exponential, uniform, and constant due dates.

b) 3, 4, 5, 9 machines pure job shop; random (RND), slack (SLK), number of operations (NOP) and total work (TWK) due dates.

c) Mean and variance of lateness, number of tardy jobs, mean and variance of flow time, number of jobs in shop, number of jobs in queues, total work content, total work remaining, imminent operation work content.

d) Defines and compares 92 different priority rules under different shop parameters.

4. Day and Hottenstein (70)

a) Exponential interarrival and processing times.

b) 5 machines pure job shop, TWK due dates, customer requested earlier due dates.

c) Fraction of tardy jobs, mean latenes, mean earliness, mean flow time, mean waiting time, mean utilisation of shop.

d) Investigates shop performance and due date performance of STOR with different arrival rates and customer requested due date changes.

5. Dudek, et al (70)

a) Actual shop data, external priority level for jobs.

b) 10-20 work centres, alternative for jobs, TWK due dates.

c) Tardiness, tardiness of high priority jobs, number of tardy jobs, work centre utilisation.

d) Compares FCFS, SIOT, EDD, STOR, STR.

6. Eilon and Chowdhury (71)

a) Constant interarrival times, normal processing times.

b) 5 machines job shop, TWK and variance of TWK due dates.

c) Mean and variance of lateness, earliness and tardiness distribution, cost of earlier and tardiness, fraction of tardy jobs, number of jobs in queues.

d) Compares FCFS and SIOT rules. Investigates effect of different due date selection rules.

7. Eilon and Hodgson (72)

a) Exponential interarrival and expected processing times, normal work rate factor.

b) 2 identical machines, single operation jobs, TWK due date.

c) Mean flow time, mean lateness, delay factor, job waiting time, queue lengths, machine idle times, number of tardy jobs, tardiness penalty.

d) Compares RANDOM, FCFS, EDD, SIOT and longest processing time rules.

8. Gere (8)
   a) Poisson arrivals, uniform processing times.
   b) 4-6 machines job shops, TWK due dates.
   c) Mean tardiness and tardiness cost.
   d) Compares simple, composite and heuristic schedule rules.

9. Holloway and Nelson (73)
   a) Static problems, uniform processing times, uniform and binomial work rate factor.
   b) 5-7 machines job shops.
   c) Mean and variance of tardiness, fraction of tardy jobs, maximum tardiness.
   d) Compares EDD, SIOT, STR and a heuristic scheduling rule.

10. Hottenstein (44)
    a) Exponential interarrival times and processing times.
    b) 6 machines pure flow shop and job shop. TWK due dates, customer requested earlier due dates, expediting.
    c) Number of jobs in the shop, fraction of tardy jobs, mean tardiness, mean flow time.
    d) Investigates FCFS and SIOT and effects of expediting in the shop.

11. Irastorza and Deane (74)
    a) Exponential interarrival and processing times, job pooling.
    b) 10 machines pure job shop, TWK due dates.
    c) Total work-in-process, total work completed, mean tardiness, variations of lateness, machine work balance index, shop work balance index, machine queue balance index.

d) Investigates effects of job pool and loading procedures on shop performance.

12. Jackson (75)
   a) Static problems, constant and empirical processing time distribution.
   b) 8 machines job shop.
   c) Mean lateness, lateness distribution.
   d) Examines a heuristic priority rule.

13. Jones (76)
   a) Adjusted arrival times for constant shop utilisation, exponential processing times.
   b) 4 machines job shop, NOP due dates.
   c) Cost of idle machines, cost of carrying work-in-process, inventory cost of long promises, cost of missed due dates.
   d) Investigates the relationships between shop utilisation, priority rules and cost components.

14. Kiran (77)
   a) Constant interarrival times, truncated - B processing times.
   b) 9 machine groups, job shop.
   c) Mean flow time, shop utilisation.
   d) Investigates effects of alternative routing, limited queue sizes, and transient conditions in job shops.

15. Kuratani and Nelson (78)
   a) Exponential interarrival and processing times.
   b) 4 machines job shop.
   c) Job flow times, queue length distribution, lateness distribution.
   d) Discuss modelling aspects of job shops, compares FCFS, SIOT, STR, and some slack based heuristic priority rules.

APPENDIX B

I The specification of product produced (adapted from "PROCON, a Production Control Exercise" by P E Galgut).

II Fig B.1 The product structure of a top mixer with its routing requirements.

III Mathematical model of the TWC method.

IV Mathematical model of the priority rules.

V Mathematical formulation of performance criteria.

I Specification of products produced *

1. Main product code

Basic:

1 Top mixer - M100/X
2 Side mixer - M200/X
X = 1, 2, or 3, according to size

Detail:

Second digit	-	number of impellers
Third digit	-	number of blades per impeller or 'OB' for balanced impeller

The material of construction of the shaft and impeller is indicated by addition of:

M = mild steel
S = stainless steel

Two further digits are added to indicate the effective length of the shaft (measured from the bearing cover) in inches.

e.g. M224/1S24 = first size of side mixer having two 4-bladed impellers, the shaft and impeller being fabricated from stainless steel, the effective length of the shaft being 24 inches.

M11OB/2M36 = second size of top mixer having one balanced impeller being fabricated from mild steel, the effective length of the shaft being 36 inches.

* Adapted from "PRODCON, a Production Control Exercise" by P E Galgut (39).

2. Sub assembly code

Basic:

Shaft and impeller - SA800/X
X = 1, 2, or 3, according to the size of mixer for which the sub assembly is intended.

Detail:

as for Product Codes.

e.g. SA814/2M36 = Shaft and impeller sub assembly for second size of mixer, having one 4-bladed impeller, the shaft and impeller being fabricated from mild steel.

3. Manufactured component codes

1. Cage

A301/2	for sizes 1 and 2 side mixers
A303	for size 3 side mixer
A311/2	for sizes 1 and 2 top mixers
A313	for size 3 top mixer

2. Impellers
   Basic : A3200

   Detail : Third digit - 1 for 8" diameter impeller
   2 for 10" diameter impeller
   3 for 12" diameter impeller

   Final digit - 2 or 4, depending upon the number of blade or B if balanced.

Material of construction is indicated by the addition of

M - Mild steel S - Stainless steel

e.g. A3214S = Stainless Steel 8" dia. 4-bladed impeller.

3. Bearing Cover A331/2 for size 1 and 2 mixers
A333 for size 3 mixers

4. Coupling A341/2 for size 1 and 2 mixers
A343 for size 3 mixers

4. Purchased parts code

1. P401 = Motors 1/4 H.P.
2. P402 = Motors 1/2 H.P.
3. P403 = Motors 3/4 H.P.
4. P501 = Gear box for size 1 mixers
5. P502 = Gear box for size 2 mixers
6. P503 = Gear box for size 3 mixers
7. P601/2 = Roller bearing for sizes 1 and 2 mixers
8. P603 = Roller bearing for size 3 mixers
9. P900 = 3/8" Whitworth bolts
10. P910 = 3/8" Whitworth nuts
11. P920 = 2BA self-tapping screws
12. P930 = 2BA Allen screws
13. P940 = 1/8" stainless steel pins
14. P950 = 3/8" washers

5. Raw materials codes

1. Steel rod

B711 - 1" dia.
B712 - 1 1/8" dia.

B716 - 2" dia.
B718 - 2 1/4" dia.
Material indicated by the addition of
M = mild steel
S = stainless steel

2. 1/8" thick steel bar

B721 - 2" wide
B722 - 2 1/4" wide
Material indicated by the addition of
M = mild steel
S = stainless steel

3. Stainless steel strip

B730 - 1/8" thick, 4 1/2" wide

4. Stainless steel tube

B741 - 10" o.d., 9 1/2" i.d.
B742 - 12" o.d., 11 1/2" i.d.
Material indicated by the addition of
M = mild steel
S = stainless steel.

5. Naval brass rod

B761 - 2" dia.
B762 - 2 1/8" dia.

Notes :
The number in parantheses
indicate the quantity of
an item reqwired.

Fig.B.1. The product structure of a top mixer with its routing requirements.

III. Mathematical model for the total work content (TWC) due date assignment method

$$d_i = a_i + 6 \ \mathrm{Max} \sum_{j \in E_{(i,r)}} (s_{ijq} + t_{ijq})$$

where,

d_i = the due date of finished product of order i

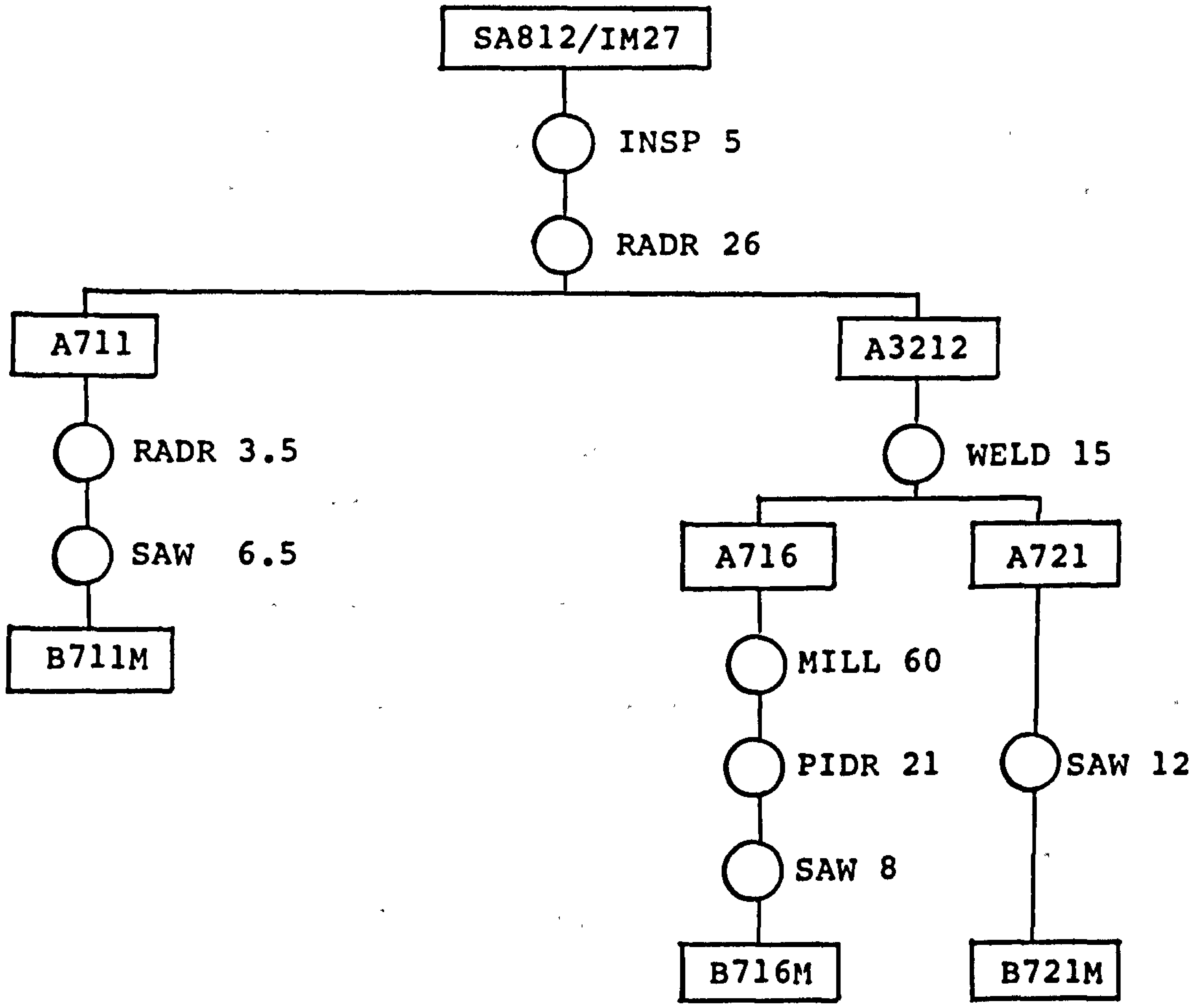
a_i = the arrival date of order i

s_{ijq} = the set up time needed in order to process part j of order i at machine q

t_{ijq} = the expected processing time of part j of order i at machine q

$E_{(i,r)}$ = the set of parts of order i which are performed through route r.

Example calculation of due date for product SA812/IM27



$$\text{Max} \sum_{j \in E_{(i,r)}} (s_{ijq} + t_{ijq}) = 8 + 21 + 60 + 15 + 26 + 5 = 135$$

IV Mathematical model for priority rules

The nomenclature used in formulation of the mathematical model is,

p_{ijq} = The priority index of part j of order i at machine q; small values of p_{ijq} have greatest priority.

a_i = The arrival date of order i.

a_{ijq} = The arrival date of part j of order i at machine q.

d_i = The due date of order i.

t_{ijq} = The expected processing time of part j of order i at machine q.

s_{ijq} = The set up time needed in order to process part j of order i at machine q.

r_{ijq} = The interoperation time of part j of order i from machine q to machine (q + 1).

$D_{(j)}$ = The set of all work stations through which part j must still pass to complete order i.

$O_{(j)}$ = The number of operations remaining through which part j must still pass to complete order i.

cd = The current date.

1. First come first served (FCFS)

The first arrival in the queue of the machine receives the highest priority, or priority rules are assigned to jobs in a strictly decreasing sequence as they arrive in a particular queue

$$p_{ijq} = a_{ijq}$$

2. Shortest imminent operation time (SIOT)

Inversely relating priority value to the processing time on the machine in question

$$p_{ijq} = s_{ijq} + t_{ijq}$$

3. Earliest due date (EDD)

Inversely relating priority value to the due date of finished product. The job with the earliest due date receives the highest priority

$$p_{ijq} = d_i$$

4. Slack time remaining (STR)

Relating priority rule directly to the remaining slack time. Highest priority is given to the job for which the time remaining to due date less the remaining processing time is a minimum

$$p_{ijq} = d_i - cd - \sum_{j \in D_{(j)}} (s_{ijq} + t_{ijq} + r_{ijq})$$

5. Slack time remaining per operation (STRO)

Relating priority value directly to the slack time per the number of operation remaining. Highest priority is assigned to the job with the smallest ratio of slack time to the number of operations remaining

$$p_{ijq} = \frac{d_i - cd - \sum (s_{ijq} + t_{ijq} + r_{ijq})}{o_j}$$

6. Critical ratio (CR)

Highest priority is given to the job with the smallest ratio between due date less the current date and the remaining processing time

$$p_{ijq} = \frac{d_i - cd}{\sum\limits_{j \in D_{(j)}} (s_{ijq} + t_{ijq} + r_{ijq})}$$

V. Mathematical model for performance criteria

Definitions of symbols used

N = number of orders completed.

ϕ = set of orders completed.

MT = the mean tardiness of job completed after their due date.

T_i = the tardiness of order i.

L_i = the lateness of order i.

c_i = the completion time of order i.

d_i = the due date of finished product i.

NT = the total number of orders tardy.

MMU = mean machine utilisation.

TA_q = the working time of machine q available.

I_q = the total idle time of machine q.

Q = the number of machines available in the system.

MOU = mean operator utilisation.

TAu = total working time of operator u available.

Iu = total idle time of operator u available.

U = number of operators available.

1. Mean tardiness

$$MT = \frac{\sum_{i=1}^{N} T_i}{N}$$

$$T_i = \max(0, L_i)$$

$$L_i = c_i - d_i$$

2. Percent tardy

$$PT = 100\ NT/N$$

$$NT = \sum_{i \in \emptyset} A_i$$

where

$$A_i = \begin{cases} 1 \text{ if } L_i > 0 \\ 0 \text{ if } L_i \leqslant 0 \end{cases}$$

3. Mean machine utilisation

$$MMU = \left[\sum_{q=1}^{Q} \frac{TA_q - I_q}{TA_q}\right] / Q$$

4. Mean operator utilisation

$$MOU = \left[\sum_{u=1}^{U} \frac{TA_u - I_u}{TA_u}\right] / U$$

APPENDIX C

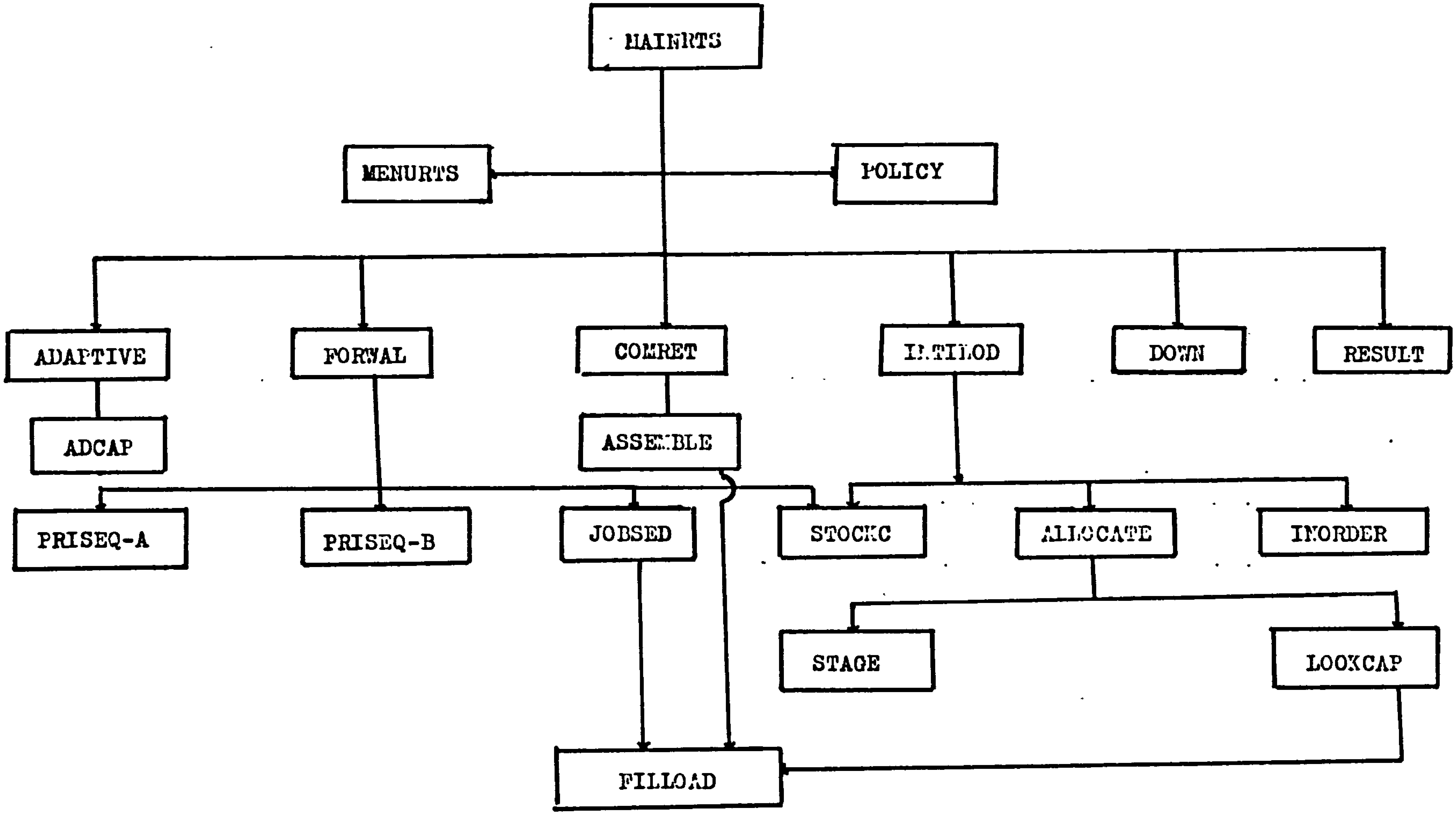


Fig.C.1. Diagram of REALTIS system

Table C.1 MASTER FILE

MASTER ADDRESS	PART CODE	PARENT POINTER	SUB ITEM POINTER	STOCK POINTER	ROUTE POINTER
001	M100/1	100	-	-	300
002	M100/2	101	-	-	300
003	M100/3	102	-	-	300
004	M200/1	103	-	-	300
005	M200/2	104	-	-	300
006	M200/3	105	-	-	300
007	A301	213	103	200	301
008	A302	214	104	201	301
009	A303	215	105	202	301
010	A311	216	100	203	302
011	A312	217	101	204	302
012	A313	218	102	205	302
013	A331	219	106	206	303
014	A332	220	107	207	303
015	A333	221	108	208	303
016	A341	222	112	209	304
017	A342	223	113	210	304
018	A343	224	114	211	305
019	SA800/X	*	166	-	*
020	P401	-	118	212	-
021	P402	-	119	213	-
022	P403	-	120	214	-
023	P501	-	124	215	-
024	P502	-	125	216	-
025	P503	-	126	217	-
026	P601	-	130	218	-
027	P602	-	131	219	-
028	P603	-	132	220	-
029	P900	-	136	221	-
030	P910	-	142	222	-
031	P920	-	148	223	-
032	P930	-	154	224	-
033	P940	-	178	225	-
034	P950	-	160	226	-
035	B711	*	168	-	310
036	B712	*	169	-	311
037	B711M	-	179	227	-
038	B711S	-	180	228	-
039	B712M	-	181	229	-
040	B712S	-	182	230	-
041	A3212	183	170	*	312
042	A3214	185	171	*	313
043	A3222	187	172	*	312
044	A3224	189	173	*	313
045	A322B	191	174	*	314
046	A3232	194	175	*	315
047	A3234	196	176	*	316
048	A323B	198	177	*	317
049	B716	*	183	-	318

Table C.1 MASTER FILE (continued)

MASTER ADDRESS	PART CODE	PARENT POINTER	SUB ITEM POINTER	STOCK POINTER	ROUTE POINTER
050	B716M	-	201	247	-
051	B716S	-	202	248	-
052	B718	*	194	-	319
053	B718M	-	203	249	-
054	B718S	-	204	250	-
055	B721	*	184	-	*
056	B721M	-	205	251	-
057	B712S	-	206	252	-
058	B722	*	195	-	*
059	B722M	-	207	253	-
060	B722S	-	208	254	-
061	B741	*	193	-	322
062	B741M	-	209	255	-
063	B741S	-	210	256	-
064	B742	*	200	-	323
065	B742M	-	211	257	-
066	B742S	-	212	258	-
067	A30	-	213	259	-
068	A31	-	216	260	-
069	B730	-	219	261	-
070	B761	-	222	262	-
071	B762	-	224	263	-

Description of MASTER file

MASTER file provides the pointers to the relevant addresses in STRUCT file, STOCK file, ROUTE file and VARIANT file. This file also contains the basic information concerning the item.

MASTER ADDRESS	= The addresses of manufacturing data of an item/component in this file.
PART CODE	= The code of an item whose manufacturing data address is stored in the associated master file address.
PARENT POINTER	= The address of product structure data of the item in the product structure data file (STRUCT) file where the item is as a parent item. * The item has a variation in terms of the parent pointer which is recorded in the VARIANT file. - The item is a bought out item. It has no address or record in STRUCT file.
SUB-ITEM POINTER	= The address of product structure data of the item in STRUCT file where the item is as a sub-item. - Where the item has never been a sub-item, it has no address or record in STRUCT file.

STOCK POINTER = The address of stock data concerning the item in the stock record (STOCK file).

* The item has a variation in terms of the stock pointer which is stored in the VARIANT file.

- Indicates that the record of the item concerned is not found in the STOCK file.

ROUTE POINTER = The address of route process data of the last manufacturing stage of the item in the route data file (ROUTE file).

* The item has a variation in terms of the route pointer which is stored in the VARIANT file.

- Indicates that the record of route process of the item is not found in the ROUTE file.

Table C.2 STRUCT FILE

ADDRESS	PARENT	SUB ITEM	MFADD	PREV PRNT ADD	NEXT PRNT ADD	PREV SITM ADD	NEXT SITM ADD	QUANT	UNIT
100	M100/1	A311	001	-	106	-	-	1.00	ea.
101	M100/2	A312	002	-	107	-	-	1.00	ea.
102	M100/3	A313	003	-	1-8	-	-	1.00	ea.
103	M200/1	A301	004	-	109	-	-	1.00	ea.
104	M200/2	A302	005	-	110	-	-	1.00	ea.
105	M200/3	A303	006	-	111	-	-	1.00	ea.
106	M100/1	A331	001	100	112	-	109	1.00	ea.
107	M100/2	A332	002	101	113	-	110	1.00	ea.
108	M100/3	A333	003	102	114	-	111	1.00	ea.
109	M200/1	A331	004	103	115	106	-	1.00	ea.
110	M200/2	A332	005	104	116	107	-	1.00	ea.
111	M200/3	A333	006	105	117	108	-	1.00	ea.
112	M100/1	A341	001	106	118	-	115	1.00	ea.
113	M100/2	A342	002	107	119	-	116	1.00	ea.
114	M100/3	A343	003	108	120	-	117	1.00	ea.
115	M200/1	A341	004	109	121	112	-	1.00	ea.
116	M200/2	A342	005	110	122	113	-	1.00	ea.
117	M200/3	A343	006	111	123	114	-	1.00	ea.
118	M100/1	P401	001	112	124	-	121	1.00	ea.
119	M100/2	P402	002	113	125	-	122	1.00	ea.
120	M100/3	P403	003	114	126	-	123	1.00	ea.
121	M200/1	P401	004	115	127	118	-	1.00	ea.
122	M200/2	P402	005	116	128	119	-	1.00	ea.
123	M200/3	P403	006	117	129	120	-	1.00	ea.
124	M100/1	P501	001	118	130	-	127	1.00	ea.
125	M100/2	P502	002	119	131	-	128	1.00	ea.
126	M100/3	P503	003	120	132	-	129	1.00	ea.
127	M200/1	P501	004	121	133	124	-	1.00	ea.
128	M200/2	P502	005	122	134	125	-	1.00	ea.
129	M200/3	P503	006	123	135	126	-	1.00	ea.
130	M100/1	P601	001	124	136	-	133	1.00	ea.
131	M100/2	P602	002	125	137	-	134	1.00	ea.
132	M100/3	P603	003	126	138	130	-	1.00	ea.
133	M200/1	P601	004	127	139	130	-	1.00	ea.
134	M200/2	P602	005	128	140	131	-	1.00	ea.
135	M200/3	P603	006	129	141	132	-	1.00	ea.
136	M100/1	P900	001	130	142	-	137	8.00	ea.
137	M100/2	P900	002	131	143	136	138	8.00	ea.
138	M100/3	P900	003	132	144	137	139	8.00	ea.
139	M200/1	P900	004	133	145	138	140	8.00	ea.
140	M200/2	P900	005	134	146	139	141	8.00	ea.
141	M200/3	P900	006	135	147	140	-	8.00	ea.
142	M100/1	P910	001	136	148	-	143	8.00	ea.
143	M100/2	P910	002	137	149	142	144	8.00	ea.
144	M100/3	P910	003	138	150	143	145	8.00	ea.
145	M200/1	P910	004	139	151	144	146	8.00	ea.
146	M200/2	P910	005	140	152	145	147	8.00	ea.
147	M200/3	P910	006	141	153	146	-	8.00	ea.

Table C.2 STRUCT FILE (continued)

ADDRESS	PARENT	SUB ITEM	MFADD	PREV PRNT ADD	NEXT PRNT ADD	PREV SITM ADD	NEXT SITM ADD	QUANT	UNIT
148	M100/1	P920	001	142	154	-	149	4.00	ea.
149	M100/2	P920	002	143	155	148	150	4.00	ea
150	M100/3	P920	003	144	156	149	151	4.00	ea.
151	M200/1	P920	004	145	157	150	152	4.00	ea.
152	M200/2	P920	005	146	158	151	153	4.00	ea.
153	M200/3	P920	006	147	159	152	-	4.00	ea.
154	M100/1	P930	001	148	160	-	155	2.00	ea.
155	M100/2	P930	002	149	161	154	156	2.00	ea.
156	M100/3	P930	003	150	162	155	157	2.00	ea.
157	M200/1	P930	004	151	163	156	158	2.00	ea.
158	M200/2	P930	005	152	164	157	159	2.00	ea.
159	M200/3	P930	006	153	165	158	-	2.00	ea.
160	M100/1	P950	001	154	166	-	161	16.00	ea.
161	M100/2	P950	002	155	166	160	162	16.00	ea.
162	M100/3	P950	003	156	166	161	163	16.00	ea.
163	M200/1	P950	004	157	167	162	164	16.00	ea.
164	M200/2	P950	005	158	167	163	165	16.00	ea.
165	M200/3	P950	006	159	167	164	-	16.00	ea.
166	M100/X	SA800/X	-	*	-	-	167	1.00	ea.
167	M200/X	SA800/X	-	*	-	166	-	1.00	ea.
168	SA800/X	B711	019	-	*	-	-	1.00	ea.
169	SA800/X	B712	019	-	*	-	-	1.00	ea.
170	SA800/X	A3212	019	*	178	-	-	0.00	ea.
171	SA800/X	A3214	019	*	178	-	-	0.00	ea.
172	SA800/X	A3222	019	*	178	-	-	0.00	ea.
173	SA800/X	A3224	019	*	178	-	-	0.00	ea.
174	SA800/X	A322B	019	*	178	-	-	1.00	ea.
175	SA800/X	A3232	019	*	178	-	-	0.00	ea.
176	SA800/X	A3234	019	*	178	-	-	0.00	ea.
177	SA800/X	A323B	019	*	178	-	-	1.00	ea.
178	SA800/X	P940	019	*	-	-	-	1.00	ea.
179	B711	B711M	035	*	-	-	-	2.50	ft.
180	B711	B711S	035	-	-	-	-	2.50	ft.
181	B712	B712M	036	-	-	-	-	2.50	ft.
182	B712	B712S	036	-	-	-	-	2.50	ft.
183	A3212	B716	041	-	184	-	185	1.00	ea.
184	A3212	B721	041	183	-	-	186	1.00	ea.
185	A3214	B716	042	-	186	183	187	1.00	ea.
186	A3214	B721	042	185	-	184	188	1.00	ea.
187	A3222	B716	043	-	188	185	189	1.00	ea.
188	A3222	B721	043	187	-	186	190	1.00	ea.
189	A3224	B716	044	-	190	187	191	1.00	ea.
190	A3224	B721	044	-	-	188	192	1.00	ea.
191	A322B	B716	045	-	192	189	-	1.00	ea.
192	A322B	B721	045	191	193	190	-	1.00	ea.
193	A322B	B741	045	192	-	-	-	1.00	ea.
194	A3232	B718	046	-	195	-	196	1.00	ea.
195	A3232	B722	046	194	-	-	197	1.00	ea.

Table C.2 STRUCT FILE (continued)

ADDRESS	PARENT	SUB ITEM	MFADD	PREV PRNT ADD	NEXT PRNT ADD	PREV SITM ADD	NEXT SITM ADD	QUANT	UNIT
196	A3234	B718	047	-	197	194	198	1.00	ea.
197	A3234	B722	047	196	-	195	199	1.00	ea.
198	A323B	B718	048	-	199	196	-	1.00	ea.
199	A323B	B722	048	198	200	197	-	1.00	ea.
200	A323B	B742	048	199	-	-	-	1.00	ea.
201	B716	B716M	049	-	-	-	-	0.30	ft.
202	B716	B716S	049	-	-	-	-	0.30	ft.
203	B718	B718M	052	-	-	-	-	0.32	ft.
204	B718	B718S	052	-	-	-	-	0.32	ft.
205	B721	B721M	055	-	-	-	-	0.85	ft.
206	B721	B721S	055	-	-	-	-	0.85	ft.
207	B722	B722M	058	-	-	-	-	1.00	ft.
208	B722	B722S	058	-	-	-	-	1.00	ft.
209	B741	B741M	061	-	-	-	-	1.00	ft.
210	B741	B741S	061	-	-	-	-	1.00	ft.
211	B742	B742M	064	-	-	-	-	1.00	ft.
212	B742	B742S	064	-	-	-	-	1.00	ft.
213	A301	A30	007	-	-	-	214	1.00	ea.
214	A302	A30	008	-	-	213	215	1.00	ea.
215	A303	A30	009	-	-	214	-	1.00	ea.
216	A311	A31	010	-	-	-	217	1.00	ea.
217	A312	A31	011	-	-	216	218	1.00	ea.
218	A313	A31	012	-	-	217	-	1.00	ea.
219	A331	B730	013	-	-	-	220	0.38	ft.
220	A332	B730	014	-	-	219	221	0.38	ft.
221	A333	B730	015	-	-	220	-	0.38	ft.
222	A341	B761	016	-	-	-	223	0.34	ft.
223	A342	B761	017	-	-	222	224	0.34	ft.
224	A343	B762	018	-	-	223	-	0.34	ft.

Description of STRUCT file

ADDRESS	= The address of parent item in this file
PARENT	= The code name of parent item
SUB-ITEM	= The code name of sub item
MFADD	= The address of the parent item in MASTER file
PREV-PRNT-ADD	= The previous address of the parent item ih this file
NEXT-PRNT-ADD	= The next address of the parent item in this file
PREV-SITM-ADD	= The previous address of the sub item in this file
NEXT-SITM-ADD	= The next address of the sub item in this file
QUANT	= The number of sub items per unit of pa - rent item
UNIT	= Unit of measure

Table C.3 ROUTE FILE

ROUTE POINTER	PART CODE	LEVEL	OP NO	W/C NO	W/C NAME	SET UP min	STND TIME min	TRANS hrs	NEXT W/C	NEXT ROUTE POINT
300	MX00/X	0	4	401	DESP	0	36	8	-	-
300	MX00/X	-	3	402	INSP	0	50	8	401	-
300	MX00/X	-	2	403	ASS	0	53	8	402	-
300	MX00/X	-	1	404	STR	0	30	8	403	-
301	A30X	1	7	412	HGRN	0	6	8	404	300
301	A30X	-	6	409	MILL	40	26	8	412	-
301	A30X	-	5	405	RADR	91	22	8	409	-
301	A30X	-	4	411	MSPD	18	2	8	405	-
301	A30X	-	3	408	PIDR	20	4	8	411	-
301	A30X	-	2	414	RGND	118	38	8	408	-
301	A30X	-	1	410	LATH	111	41	8	414	-
302	A31X	1	6	412	HGRN	0	6	8	404	300
302	A31X	-	5	409	MILL	35	26	8	412	-
302	A31X	-	4	405	RADR	12	22	8	409	-
302	A31X	-	3	411	MSPD	8	2	8	405	-
302	A31X	-	2	408	PIDR	15	4	8	411	-
302	A31X	-	1	410	LATH	40	57	8	408	-
303	A33X	1	3	411	MSPD	12	1	8	404	300
303	A33X	-	2	408	PIDR	12	1	8	411	-
303	A33X	-	1	413	RMPS	80	2	8	408	-
304	A34X	1	3	405	RADR	15	6	8	404	300
304	A34X	-	2	408	PIDR	20	8	8	405	-
304	A34X	-	1	406	SAW	0	8	8	408	-
305	A343	1	3	405	RADR	15	6	8	404	300
305	A343	-	2	408	PIDR	20	8	8	405	-
305	A343	-	1	406	SAW	0	9	8	408	-
306	SA800.12	1	1	405	RADR	18	11	8	404	300
307	SA800.3	1	1	405	RADR	18	13	8	404	300
308	SA800.2	1	1	405	RADR	34	13	8	404	300
309	SA800.3	1	1	405	RADR	34	14	8	404	300
309	B711	2	2	405	RADR	3	0	8	405	**
310	B711	-	1	406	SAW	0	6	8	405	-
311	B712	2	2	405	RADR	3	0	8	405	**
311	B712	-	1	406	SAW	0	8	8	405	-
312	A3212/22	2	1	407	WELD	0	15	8	405	306
313	A3214/24	2	1	407	WELD	0	25	8	405	306
314	A322B	2	1	407	WELD	0	53	8	405	308
315	A3232	2	1	407	WELD	0	15	8	405	307
316	A3234	2	1	407	WELD	0	25	8	405	307
317	A323B	2	1	407	WELD	0	55	8	405	309
318	B716	3	3	409	MILL	40	20	8	407	*
318	B716	-	2	408	PIDR	12	9	8	409	-
318	B716	-	1	406	SAW	0	8	8	408	-
319	B718	3	3	409	MILL	40	22	8	407	*
319	B718	-	2	408	PIDR	12	10	8	409	-
319	B718	-	1	406	SAW	0	9	8	408	-
320	B721	3	1	406	SAW	0	14	8	407	*
321	B722	3	1	406	SAW	0	14	8	407	*

Table C.3 ROUTE FILE (continued)

ROUTE POINTER	PART CODE	LEVEL	OP NO	W/C NO	W/C NAME	SET UP min	STND TIME min	TRANS hrs	NEXT W/C	NEXT ROUTE POINT
322	B741	3	1	406	SAW	0	11	8	407	314
323	B742	3	1	406	SAW	0	14	8	407	317
324	B721	3	2	415	GRND	80	32	8	407	314
324	B721	-	1	406	SAW	0	8	8	415	-
325	B722	3	2	415	GRND	80	34	8	407	317
325	B722	-	1	406	SAW	0	12	8	415	-

ROUTE POINTER	= The address where the data concerning the manufacturing route of the item is stored
PART CODE	= The code of the item
LEVEL	= The level of the item according to the product structure
OP-NO	= The sequence number of the manufacturing stage of the item
W/C-NO	= The identification of the work centre
SET UP	= The standard set up time required in order to process the item in the associated work centre
STND-TIME	= The standard operation time per unit of the item
TRANS	= Time taken to transfer an item from one work centre to another work centre
NEXT-W/C	= The next work centre number where the item is to be processed
NEXT-ROUTE-POINT	= The address where the data for the next manufacturing stage of the item is stored

Table C.4 VARIANT FILE

PART CODE	MATE RIAL	PARENT POINTER	NEXT PARENT ADD	IMPEL	BLADE	SIZE	STOCK POINTER	NEXT ROUTE POINT
SA800/X	-	168	-	-	-	1	-	-
SA800/X	-	169	-	-	-	3	-	-
SA800/X	-	-	170	1	2	1	-	-
SA800/X	-	-	170	2	2	1	-	-
SA800/X	-	-	171	1	4	1	-	-
SA800/X	-	-	171	2	4	1	-	-
SA800/X	-	-	172	1	2	2	-	-
SA800/X	-	-	172	2	2	2	-	-
SA800/X	-	-	172	3	2	2	-	-
SA800/X	-	-	173	1	4	2	-	-
SA800/X	-	-	173	2	4	2	-	-
SA800/X	-	-	173	3	4	2	-	-
SA800/X	-	-	174	1	B	2	-	-
SA800/X	-	-	175	1	2	3	-	-
SA800/X	-	-	175	2	2	3	-	-
SA800/X	-	-	175	3	2	3	-	-
SA800/X	-	-	176	1	4	3	-	-
SA800/X	-	-	176	2	4	3	-	-
SA800/X	-	-	176	3	4	3	-	-
SA800/X	-	-	177	1	B	3	-	-
B711	M	179	-	-	-	-	-	-
B711	S	180	-	-	-	-	-	-
B712	M	181	-	-	-	-	-	-
B712	S	182	-	-	-	-	-	-
B716	M	201	-	-	-	-	-	-
B716	S	202	-	-	-	-	-	-
B718	M	203	-	-	-	-	-	-
B718	S	204	-	-	-	-	-	-
B721	M	205	-	-	-	-	-	-
B721	S	206	-	-	-	-	-	-
B722	M	207	-	-	-	-	-	-
B722	S	208	-	-	-	-	-	-
B741	M	209	-	-	-	-	-	-
B741	S	210	-	-	-	-	-	-
B742	M	211	-	-	-	-	-	-
B742	S	212	-	-	-	-	-	-
SA800/X	-	168	-	-	-	2	-	-
A3212	M	-	-	-	-	-	231	-
A3212	S	-	-		-	-	232	-
A3214	M	-	-	-	-	-	233	-
A3214	S	-	-	-	-	-	234	-
A3222	M	-	-	-	-	-	235	-
A3222	S	-	-	-	-	-	236	-
A3224	M	-	-	-	-	-	237	-
A3224	S	-	-	-	-	-	238	-
A322B	M	-	-	-	-	-	239	-
A322B	S	-	-	-	-	-	240	-
A3232	M	-	-	-	-	-	241	-

Table C.4 VARIANT FILE (continued)

PART CODE	MATE RIAL	PARENT POINTER	NEXT PARENT ADD	IMPEL	BLADE	SIZE	STOCK POINTER	NEXT ROUTE POINT
A3232	S	-	-	-	-	-	242	-
A3234	M	-	-	-	-	-	243	-
A3234	S	-	-	-	-	-	244	-
A323B	M	-	-	-	-	-	245	-
A323B	S	-	-	-	-	-	246	-
B716	-	-	-	-	2	1	-	312
B716	-	-	-	-	4	1	-	313
B716	-	-	-	-	4	2	-	313
B716	-	-	-	-	B	2	-	314
B718	-	-	-	-	2	3	-	315
B718	-	-	-	-	4	3	-	316
B718	-	-	-	-	B	3	-	317
B721	-	-	-	-	4	1	-	313
B721	-	-	-	-	4	2	-	313
B721	-	-	-	-	B	2	-	314
B722	-	-	-	-	2	3	-	315
B722	-	-	-	-	4	3	-	316
B722	-	-	-	-	B	3	-	317
B716	-	-	-	-	2	2	-	312
B721	-	-	-	-	2	1	-	312
B721	-	-	-	-	2	2	-	312
B711	-	-	-	-	-	1	-	306
B711	-	-	-	-	-	2	-	306
B711	-	-	-	-	B	2	-	308
B711	-	-	-	-	B	3	-	309
B712	-	-	-	-	-	3	-	307
B712	-	-	-	-	B	3	-	309

Table C.5 CAPACITY FILE

W/C NO. : 406 [SAW]
3 unit (36hrs/unit/wk)

WEEK NO.	CAPACITY USED [hrs]	CAPACITY AVAILABLE [hrs]
1	99	9
2	105	3
3	108	0
4	81	27
5	0	108
6	0	108
7	0	108
8	0	108
9	0	108
10	0	108
11	0	108
12	0	108
13	0	108
14	0	108
15	0	108
16	0	108
17	0	108
18	0	108
19	0	108
20	0	108
21	0	108
22	0	108
23	0	108
24	0	108
25	0	108
26	0	108
27	0	108
28	0	108
29	0	108
30	0	108
31	0	108
32	0	108
33	0	108
34	0	108
35	0	108
36	0	108
37	0	108
38	0	108
39	0	108
40	0	108

Table C.6 STOCK FILE

STOCK POINT	PART CODE	PHYSICAL STOCK	ON ORDER	ALLOCATION	POTENTIAL STOCK	FREE STOCK	REORD LEVEL	ORDER SIZE
212	P401	500	0	73	500	427	300	500
213	P402	500	0	76	500	424	300	500
214	P403	500	0	74	500	426	300	500
215	P501	500	0	73	500	427	300	500
216	P502	500	0	76	500	424	300	500
217	P503	500	0	74	500	426	300	500
218	P601	500	0	73	500	427	300	500
219	P602	500	0	76	500	424	300	500
220	P603	500	0	74	500	426	300	500
221	P900	4000	4000	1784	8000	6216	2400	4000
222	P910	4000	4000	1784	8000	6216	2400	4000
223	P920	2000	2000	892	4000	3108	1200	2000
224	P930	1000	1000	446	2000	1554	600	1000
225	P940	447	500	281	977	696	300	500
226	P950	8000	8000	3568	16000	12432	4800	8000
227	B711M	881	0	57	881	824	600	1000
228	B711S	865	0	127	865	738	600	1000
229	B712M	881	0	135	881	746	600	1000
230	B712S	935	0	0	935	935	600	1000
247	B716M	458	0	6	458	452	300	500
248	B716S	439	0	0	439	439	300	500
249	B718M	459	0	8	459	451	300	500
250	B718S	484	0	0	484	484	300	500
251	B721M	379	0	19	379	360	300	500
252	B721S	347	0	22	347	325	300	500
253	B722M	365	0	26	365	339	300	500
254	B722S	448	0	0	448	448	300	500
255	B741M	500	0	0	500	500	300	500
256	B741S	500	0	0	500	500	300	500
257	B742M	472	0	26	472	446	300	500
258	B742S	500	0	0	500	500	300	500
259	A30	380	0	23	380	357	300	500
260	A31	367	0	38	367	329	300	500
261	B730	383	0	0	383	383	300	500
262	B761	446	0	15	446	431	300	500
263	B762	447	0	0	477	477	300	500

APPENDIX D

TABLE D.1 MEAN TARDINESS

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	0.19	0.12	0.08	0.16	0.20
a1b1c1d2	0.15	0.19	0.17	0.12	0.23
a1b1c2d1	0.11	0.08	0.16	0.09	0.17
a1b1c2d2	0.19	0.13	0.12	0.13	0.17
a1b2c1d1	0.75	0.67	0.69	0.40	0.79
a1b2c1d2	0.65	0.73	0.76	0.72	0.73
a1b2c2d1	0.21	0.19	0.16	0.20	0.20
a1b2c2d2	0.16	0.20	0.16	0.20	0.11
a1b3c1d1	0.75	0.69	0.40	0.67	0.67
a1b3c1d2	0.16	0.20	0.15	0.12	0.48
a1b3c2d1	0.12	0.12	0.48	0.08	0.79
a1b3c2d2	0.12	0.58	0.09	0.16	0.45
a1b4c1d1	0.79	0.23	0.12	0.58	0.17
a1b4c1d2	0.16	0.16	0.12	0.12	0.19
a1b4c2d1	0.12	0.79	0.16	0.67	0.19
a1b4c2d2	0.12	0.05	0.19	0.12	0.76
a1b5c1d1	0.04	0.03	0.08	0.01	0.01
a1b5c1d2	0.08	0.03	0.03	0.01	0.01
a1b5c2d1	0.01	0.03	0.03	0.08	0.01
a1b5c2d2	0.01	0.08	0.01	0.03	0.01
a1b6c1d1	0.19	0.20	0.13	0.20	0.79
a1b6c1d2	0.11	0.12	0.39	0.16	0.16
a1b6c2d1	0.16	0.09	0.08	0.58	0.05
a1b6c2d2	0.45	0.15	0.09	0.08	0.79
a2b1c1d1	0.17	0.17	0.11	0.15	0.19
a2b1c1d2	0.13	0.16	0.12	0.15	0.15
a2b1c2d1	0.15	0.16	0.16	0.13	0.13
a2b1c2d2	0.16	0.12	0.21	0.17	0.20
a2b2c1d1	0.75	0.67	0.69	0.56	0.44
a2b2c1d2	0.19	0.19	0.12	0.08	0.09
a2b2c2d1	0.16	0.72	0.56	0.69	0.79
a2b2c2d2	0.39	0.13	0.21	0.09	0.15
a2b3c1d1	0.51	0.73	0.75	0.69	0.67
a2b3c1d2	0.20	0.17	0.13	0.16	0.08
a2b3c2d1	0.17	0.01	0.08	0.08	0.08
a2b3c2d2	0.16	0.24	0.16	0.19	0.09
a2b4c1d1	0.29	0.75	0.20	0.20	0.24
a2b4c1d2	0.79	0.12	0.39	0.21	0.23
a2b4c2d1	0.15	0.40	0.12	0.12	0.16
a2b4c2d2	0.20	0.12	0.13	0.17	0.35

TABLE D.1 MEAN TARDINESS (continued)

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a2b5c1d1	0.03	0.03	0.01	0.03	0.01
a2b5c1d2	0.08	0.03	0.03	0.05	0.03
a2b5c2d1	0.03	0.04	0.03	0.01	0.03
a2b5c2d2	0.01	0.05	0.01	0.03	0.05
a2b6c1d1	0.17	0.16	0.12	0.05	0.09
a2b6c1d2	0.15	0.15	0.19	0.13	0.17
a2b6c2d1	0.09	0.08	0.11	0.17	0.05
a2b6c2d2	0.15	0.08	0.09	0.20	0.05

a1 = TWC
a2 = MRP
b1 = CR
b2 = FCFS
b3 = SIOT
b4 = EDD
b5 = STR
b6 = STRO
c1 = FPB
c2 = VPB
d1 = COR
d2 = DOR

TABLE D.2 PERCENT TARDY

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	4.00	4.00	2.67	4.00	4.00
a1b1c1d2	5.33	5.33	5.33	2.67	1.33
a1b1c2d1	5.33	4.00	8.00	5.33	8.00
a1b1c2d2	9.33	8.00	4.00	4.00	5.33
a1b2c1d1	10.67	8.00	14.67	5.33	13.33
a1b2c1d1	10.67	9.33	16.00	9.33	16.00
a1b2c2d1	9.33	9.33	5.33	5.33	8.00
a1b2c2d2	5.33	5.33	9.33	8.00	4.00
a1b3c1d1	10.67	14.67	5.33	8.00	14.67
a1b3c1d2	4.00	4.00	5.33	4.00	10.67
a1b3c2d1	2.67	4.00	10.67	4.00	13.33
a1b3c2d2	2.67	10.67	4.00	8.00	10.67
a1b4c1d1	13.33	9.33	5.33	10.67	5.33
a1b4c1d2	5.33	5.33	4.00	2.67	4.00
a1b4c2d1	4.00	13.33	9.33	8.00	4.00
a1b4c2d2	4.00	4.00	5.33	2.67	16.00
a1b5c1d1	2.67	1.33	2.67	1.33	1.33
a1b5c1d2	2.67	1.33	1.33	1.33	1.33
a1b5c2d1	1.33	1.33	2.67	2.67	1.33
a1b5c2d2	1.33	2.67	1.33	1.33	1.33
a1b6c1d1	5.33	4.00	5.33	8.00	13.33
a1b6c1d2	5.33	2.67	9.33	8.00	5.33
a1b6c2d1	5.33	4.00	5.33	10.67	4.00
a1b6c2d2	10.67	5.33	5.33	5.33	13.33
a2b1c1d1	5.33	5.33	2.67	4.00	5.33
a2b1c1d2	4.00	5.33	2.67	4.00	2.67
a2b1c2d1	2.67	5.33	8.00	4.00	5.33
a2b1c2d2	5.33	8.00	8.00	5.33	9.33
a2b2c1d1	10.67	14.67	14.67	13.33	8.00
a2b2c1d2	9.33	9.33	5.33	5.33	4.00
a2b2c2d1	4.00	14.67	13.33	14.67	13.33
a2b2c2d2	9.33	5.33	8.00	5.33	8.00
a2b3c1d1	9.33	5.33	10.67	14.67	14.67
a2b3c1d2	4.00	5.33	5.33	8.00	5.33
a2b3c2d1	5.33	1.33	5.33	4.00	4.00
a2b3c2d2	5.33	8.00	8.00	5.33	4.00
a2b4c1d1	5.33	10.67	8.00	8.00	5.33
a2b4c1d2	13.33	4.00	9.33	5.33	9.33
a2b4c2d1	5.33	10.67	4.00	2.67	4.00
a2b4c2d2	8.00	4.00	8.00	5.33	9.33
a2b5c1d1	1.33	2.67	1.33	1.33	1.33
a2b5c1d2	2.67	1.33	2.67	2.67	2.67
a2b5c2d1	2.67	2.67	2.67	1.33	1.33
a2b5c2d2	1.33	4.00	1.33	2.67	2.67
a2b6c1d1	8.00	4.00	2.67	5.33	5.33
a2b6c1d2	2.67	4.00	5.33	9.33	8.00
a2b6c2d1	4.00	4.00	5.33	8.00	4.00
a2b6c2d2	8.00	2.67	5.33	4.00	5.33

TABLE D.3 ROOT MEAN SQUARE (RMS) OF TARDINESS

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	4.69	4.12	3.60	4.50	5.74
a1b1c1d2	2.69	3.81	3.27	5.15	4.27
a1b1c2d1	2.65	2.16	2.71	2.06	3.44
a1b1c2d2	2.87	2.00	3.70	3.37	3.64
a1b2c1d1	8.84	9.54	9.62	12.67	8.51
a1b2c1d2	7.22	9.26	7.07	9.62	8.77
a1b2c2d1	3.89	2.56	2.93	3.42	4.18
a1b2c2d2	2.93	3.42	2.45	4.18	2.94
a1b3c1d1	8.84	7.19	12.67	9.54	7.34
a1b3c1d2	4.50	5.74	2.45	5.63	6.67
a1b3c2d1	5.15	4.12	6.20	3.16	7.49
a1b3c2d2	4.74	6.82	3.00	2.71	6.57
a1b4c1d1	7.49	4.25	3.12	6.82	3.27
a1b4c1d2	3.16	4.09	3.70	5.15	4.69
a1b4c2d1	4.12	8.51	2.45	9.54	4.69
a1b4c2d2	3.42	1.41	4.18	5.15	7.02
a1b5c1d1	1.58	2.00	3.00	1.00	1.00
a1b5c1d2	3.00	1.41	2.00	1.00	1.00
a1b5c2d1	1.00	2.00	1.00	3.00	1.00
a1b5c2d2	1.00	3.00	1.00	2.00	1.00
a1b6c1d1	4.12	6.14	2.92	4.18	7.49
a1b6c1d2	3.56	5.15	6.12	2.52	3.87
a1b6c2d1	4.66	2.42	1.73	6.82	1.41
a1b6c2d2	6.57	4.09	2.06	1.73	7.49
a2b1c1d1	3.24	1.66	4.12	3.70	4.18
a2b1c1d2	3.46	3.00	4.74	3.70	3.28
a2b1c2d1	2.61	3.16	2.45	3.37	2.60
a2b1c2d2	3.00	1.87	1.83	3.50	2.27
a2b2c1d1	8.84	7.34	7.19	6.08	7.11
a2b2c1d2	2.56	3.89	3.12	1.73	2.42
a2b2c2d1	4.49	7.22	6.08	7.19	8.51
a2b2c2d2	5.71	2.92	3.97	2.65	2.61
a2b3c1d1	7.56	8.77	8.84	7.19	7.34
a2b3c1d2	5.74	3.27	2.92	2.45	1.73
a2b3c2d1	3.37	1.00	1.71	2.16	2.16
a2b3c2d2	3.16	4.47	2.71	4.18	3.00
a2b4c1d1	5.27	8.83	2.97	2.97	3.67
a2b4c1d2	8.51	4.12	6.12	5.30	3.58
a2b4c2d1	4.09	6.06	5.63	5.15	4.50
a2b4c2d2	2.97	5.63	2.08	3.97	6.17
a2b5c1d1	2.00	1.00	1.00	2.00	1.00
a2b5c1d2	3.00	2.00	1.00	2.23	1.00
a2b5c2d1	1.00	1.58	1.00	1.00	2.00
a2b5c2d2	1.00	1.41	1.00	1.00	2.23
a2b6c1d1	3.39	4.50	5.15	1.00	2.50
a2b6c1d2	3.28	2.16	4.20	1.77	3.39
a2b6c2d1	2.51	2.16	2.70	3.39	1.41
a2b2c2d2	2.61	3.00	2.50	5.71	1.00

TABLE D.4 MEAN WORK IN PROGRESS (WIP)

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	4.51	5.20	4.30	5.10	4.40
a1b1c1d2	3.98	2.95	4.20	3.47	5.27
a1b1c2d1	1.74	2.75	3.02	2.40	1.84
a1b1c2d2	1.35	1.64	2.12	1.83	1.74
a1b2c1d1	7.30	4.54	6.14	7.10	5.37
a1b2c1d2	4.75	3.10	5.35	3.82	4.08
a1b2c2d1	2.51	3.35	2.10	2.10	3.04
a1b2c2d2	1.55	1.67	2.14	1.84	1.80
a1b3c1d1	7.13	6.32	4.94	5.46	5.10
a1b2c1d2	3.60	4.23	3.82	5.10	3.90
a1b3c2d1	1.03	2.40	1.50	1.45	2.07
a1b3c2d2	1.68	1.25	2.16	1.10	1.51
a1b4c1d1	2.36	4.45	3.10	3.75	4.09
a1b4c1d2	4.97	2.17	4.10	3.15	3.86
a1b4c2d1	1.20	3.20	2.10	1.95	1.80
a1b4c2d2	2.91	1.74	3.20	2.10	2.15
a1b5c1d1	3.89	4.15	3.84	3.75	2.87
a1b5c1d2	3.21	3.40	3.13	4.37	2.84
a1b5c2d1	3.16	3.10	2.15	1.75	1.89
a1b5c2d2	3.09	2.15	2.18	1.81	2.12
a1b6c1d1	4.22	4.13	3.17	2.83	3.85
a1b6c1d2	2.46	3.06	2.97	4.04	2.67
a1b6c2d1	2.22	1.74	3.05	2.50	2.49
a1b6c2d2	2.21	2.15	1.57	2.60	2.47
a2b1c1d1	2.12	3.64	2.54	1.76	2.04
a2b1c1d2	3.97	2.64	2.17	3.09	1.83
a2b1c2d1	2.24	1.68	2.09	2.04	2.50
a2b1c2d2	2.25	2.30	2.60	1.75	3.10
a2b2c1d1	3.12	3.44	2.78	2.40	1.86
a2b2c1d2	3.46	2.71	4.08	2.02	2.78
a2b2c2d1	2.50	2.47	2.60	3.16	1.87
a2b2c2d2	1.97	1.67	1.82	1.34	1.20
a2b3c1d1	3.54	1.82	2.76	4.45	3.88
a2b3c1d2	2.51	4.15	3.04	2.85	3.20
a2b3c2d1	1.26	1.70	2.07	1.20	1.42
a2b3c2d2	1.81	1.32	1.40	1.10	1.72
a2b4c1d1	2.09	3.05	2.47	2.10	3.04
a2b4c1d2	3.13	2.84	3.06	2.97	2.60
a2b4c2d1	2.01	1.45	2.08	2.37	1.84
a2b4c2d2	2.02	2.42	3.05	1.67	2.54
a2b5c1d1	1.10	3.34	2.17	3.10	2.45
a2b5c1d2	3.25	2.43	2.60	3.15	1.87
a2b5c2d1	1.53	2.57	3.08	2.10	2.12
a2b5c2d2	3.10	2.20	2.47	3.04	1.69
a2b6c1d1	3.41	2.70	3.50	2.84	3.05
a2b6c1d2	3.27	2.74	2.65	1.84	2.90
a2b6c2d1	1.71	1.85	2.54	1.93	3.12
a2b6c2d2	2.60	2.27	2.68	1.54	1.76

TABLE D.5 MEAN MACHINE UTILISATION

POLICY	RUN 1	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	68.43	72.12	69.54	71.34	68.37
a1b1c1d2	72.56	76.10	73.54	74.80	76.23
a1b1c2d1	78.21	79.06	80.10	79.34	79.33
a1b1c2d2	78.45	78.73	77.57	79.23	78.47
a1b2c1d1	74.56	76.60	74.27	69.64	72.48
a1b2c1d2	74.76	76.83	72,63	73.07	75.65
a1c2c2d1	75.21	80.04	77.42	79.89	79.02
a1b2c2d2	80.02	81.27	78.01	78.45	78.75
a1b3c1d1	73.98	68.45	74.26	70.04	75.62
a1b3c1d2	73.84	75.67	69.17	72.87	76.35
a1b3c2d1	77.59	80.39	79.73	78.45	76.29
a1b3c2d2	76.47	78.43	79.75	76.48	76.86
a1b4c1d1	74.45	75.98	77.39	71.10	71.43
a1b4c1d2	75.12	73.47	72.76	77.47	73.35
a1b4c2d1	79.04	80.03	78.09	79.34	79.82
a1b4c2d2	78.53	78.03	79.51	77.36	78.54
a1b5c1d1	73.42	77.39	73.28	74.61	78.19
a1b5c1d2	75.27	75.36	76.48	72.37	73.45
a1b5c2d1	79.75	76.64	79.43	77.11	79.53
a1b5c2d2	80.77	80.57	78.65	79.65	78.67
a1b6c1d1	73.34	75.77	73.45	76.55	73.78
a1b6c1d2	73.06	77.70	76.67	77.54	77.50
a1b6c2d1	79.56	78.90	79.70	80.36	79.52
a1b6c2d2	76.67	79.22	78.34	77.79	79.81
a2b1c1d1	78.55	77.65	74.34	73.25	68.57
a2b1c1d2	74.88	77.65	77.43	78.94	79.07
a2b1c2d1	80.57	80.01	80.23	77.52	78.52
a2b1c2d2	80.50	81.64	76.76	80.63	78.55
a2b2c1d1	76.56	71.45	76.53	74.86	78.54
a2b2c1d2	78.96	76.94	77.44	77.05	77.27
a2b2c2d1	79.74	79.05	77.04	75.51	79.54
a2b2c2d2	80.54	79.43	78.64	79.65	79.77
a2b3c1d1	71.17	77.65	77.43	76.58	74.72
a2b3c1d2	77.66	75.08	74.05	77.07	77.03
a2b3c2d1	80.02	78.87	78.57	77.44	77.03
a2b3c2d2	81.02	78.50	78.05	79.84	79.91
a2b4c1d1	78.65	74.76	69.94	77.90	77.07
a2b4c1d2	82.03	80.60	79.61	65.80	80.67
a2b4c2d1	77.87	78.95	76.54	75.45	79.53
a2b4c2d2	74.76	79.64	80.65	78.66	79.21
a2b5c1d1	84.48	81.11	82.92	84.21	84.33
a2b5c1d2	78.67	79.54	76.55	76.15	76.58
a2b5c2d1	75.47	78.96	79.88	78.75	80.05
a2b5c2d2	80.43	80.66	79.65	78.07	78.88
a2b6c1d1	70.04	73.21	68.24	75.45	69.91
a2b6c1d2	75.44	74.42	78.61	75.55	78.28
a2b6c2d1	79.34	79.33	80.06	78.53	79.44
a2b6c2d2	72.11	78.23	79.35	80.03	81.52

TABLE D.6 MEAN OPERATOR UTILISATION

POLICY	RUN I	RUN II	RUN III	RUN IV	RUN V
a1b1c1d1	81.12	82.43	79.47	81.32	78.36
a1b1c1d2	82.50	86.12	78.45	84.06	86.23
a1b1c2d1	78.13	87.69	83.10	88.34	86.33
a1b1c2d2	88.54	88.75	87.57	84.23	85.73
a1b2c1d1	83.87	80.70	84.72	81.64	82.48
a1b2c1d2	84.76	82.83	93.63	83.70	85.56
a1b2c2d1	87.12	88.04	87.42	84.89	87.02
a1b2c2d2	85.02	84.77	83.15	85.67	73.56
a1b3c1d1	83.48	84.46	83.37	84.43	81.28
a1b3c1d2	83.74	85.67	81.37	80.72	80.54
a1b3c2d1	87.90	83.97	85.47	86.45	84.65
a1b3c2d2	86.47	88.45	83.86	86.45	86.26
a1b4c1d1	84.55	79.45	78.24	80.35	81.32
a1b4c1d2	85.31	81.23	82.76	82.53	83.05
a1b4c2d1	87.75	84.94	87.54	86.65	86.63
a1b4c2d2	87.56	87.23	85.31	86.55	85.93
a1b5c1d1	81.23	81.34	82.33	80.35	81.05
a1b5c1d2	80.34	81.65	80.32	80.06	80.21
a1b5c2d1	87.64	86.65	85.82	84.75	85.08
a1b5c2d2	84.76	86.55	85.53	86.43	85.76
a1b6c1d1	83.75	80.90	84.86	82.13	83.07
a1b6c1d2	84.34	82.76	80.22	82.54	83.56
a1b6c2d1	87.86	84.54	85.44	86.78	85.66
a1b6c2d2	87.43	85.57	86.43	87.48	86.77
a2b1c1d1	84.42	82.47	83.81	84.41	82.85
a2b1c1d2	82.76	82.06	83.24	80.31	84.07
a2b1c2d1	86.65	87.52	87.54	85.55	86.57
a2b1c2d2	85.05	86.78	86.08	87.29	85.21
a2b2c1d1	85.35	83.71	84.37	84.82	85.36
a2b2c1d2	83.76	82.04	84.75	82.56	83.18
a2b2c2d1	87.48	86.33	85.07	86.51	87.03
a2b2c2d2	86.43	87.63	85.75	87.54	86.35
a2b3c1d1	85.56	83.89	84.35	85.07	84.23
a2b3c1d2	82.34	83.12	84.54	82.21	81.97
a2b3c2d1	84.54	86.33	82.44	85.02	83.07
a2b3c2d2	83.81	80.55	84.53	83.08	82.14
a2b4c1d1	84.56	82.11	82.54	84.32	83.42
a2b4c1d2	82.37	84.07	83.15	82.46	83.52
a2b4c2d1	87.32	86.84	86.54	85.24	86.36
a2b4c2d2	87.42	85.39	86.73	86.54	87.18
a2b5c1d1	82.37	84.64	82.52	83.34	83.61
a2b5c1d2	82.54	84.32	81.63	82.12	83.52
a2b5c2d1	87.57	86.33	87.42	85.07	86.20
a2b5c2d2	86.23	84.32	85.31	86.03	85.53
a2b6c1d1	80.50	84.52	82.16	83.11	82.94
a2b6c1d2	82.54	83.07	83.77	81.54	83.42
a2b6c2d1	86.31	87.22	84.26	84.30	85.66
a2b6c2d2	85.51	87.06	85.43	86.38	86.16

Table D.7 Percentage Points of the F Distribution

$$F_{0.01, v_1, v_2}$$

Degrees of freedom for the numerator (v_1); rows: Degrees of freedom for the denominator (v_2)

v_2 \ v_1	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	4052	4999.5	5403	5625	5764	5859	5928	5982	6022	6056	6106	6157	6209	6235	6261	6287	6313	6339	6366
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40	99.42	99.43	99.45	99.46	99.47	99.47	99.48	99.49	99.50
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23	27.05	26.87	26.69	26.00	26.50	26.41	26.32	26.22	26.13
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55	14.37	14.20	14.02	13.93	13.84	13.75	13.65	13.56	13.46
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.86
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	8.68	6.36	5.42	4.89	4.36	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22	3.13	2.99	2.85	2.70	2.62	2.54	2.45	2.36	2.27	2.17
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09	2.96	2.81	2.66	2.58	2.50	2.42	2.33	2.23	2.13
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06	2.93	2.78	2.63	2.55	2.47	2.38	2.29	2.20	2.10
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03	2.90	2.75	2.60	2.52	2.44	2.35	2.26	2.17	2.06
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00	2.87	2.73	2.57	2.49	2.41	2.33	2.23	2.14	2.03
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

APPENDIX E

THE COMPARISON TEST ON THE MEANS OF TREATMENTS

The comparison test on the means of treatments using the Duncan's method includes,

E.1. The comparison test of the treatments' means

E.2. Discussion on the result of the test.

E.1. The comparison test of the treatments' means

During the test, it would be assumed that the best estimate of the error variance is the means square of error (MS error) of the analysis of variance; utilising the assumption that the experimental error is the same over all treatment combinations. The standard error of these treatments' means can be calculated as follows

$$Sy_m = \sqrt{\frac{\text{MS error}}{n}}$$

where, sy_m = the standard error of the treatment y_m

MS error = the mean square of error obtained from the ANOVA table

n = number of observations in order to obtain each mean of treatment.

Due to the similarity of the testing procedure for the comparison test on the means of each interaction, here is only given one example, namely the comparison test of means of AB interaction in terms of RMS of tardiness performance. Further, for the other interactions, are only shown the tables of each of the means of interaction and the comparison table of the means. Following the Duncan multiple range test in Chapter VI, the comparison of the means of AB interaction shown in Table E.1 could be carried out as follows.

1. The means of AB interaction are arranged in ascending order, as shown in Table E.2.

2. Obtain the value of the error mean square, (MS error) from Table VII.5.

   MS error = 1.89 with 192 degrees of freedom.

3. The standard error of a mean is,

$$s\bar{y}_i = \sqrt{\frac{\text{MS error}}{n}} = \sqrt{\frac{1.89}{20}} = 0.31$$

4. From Table E.44, at the 5 percent level ($\alpha = 0.05$) and the degree of freedom (f) = 192, the significant ranges $r_{\alpha}(p,f)$ are

p	$r_{0.05}(p,192)$	p	$r_{0.05}(p,192)$
2	2.77	8	3.23
3	2.92	9	3.28
4	3.02	10	3.29
5	3.09	11	3.31
6	3.15	12	3.33
7	3.19		

5. Obtain the least significant ranges (LSR) by multiplying the standard error of 0.31 with each value of the significant ranges obtained in Step 4.

TABLE E.1 MEANS OF THE INTERACTION BETWEEN FACTORS A AND B FOR RMS OF TARDINESS

FACTOR LEVEL a_i	b_j	MEANS	FACTOR LEVEL a_i	b_j	MEANS
a_1	b_1	3.52	a_2	b_1	3.09
a_1	b_2	6.20	a_2	b_2	5.10
a_1	b_3	6.03	a_2	b_3	4.19
a_1	b_4	4.81	a_2	b_4	4.88
a_1	b_5	1.65	a_2	b_5	1.48
a_1	b_6	4.25	a_2	b_6	2.90

* The calculations were based on data in Table D.3

TABLE E.2 MEANS OF INTERACTION BETWEEN FACTORS A AND B FOR RMS OF TARDINESS IN ASCENDING ORDER

FACTOR LEVEL a_i	b_j	Y_m	MEANS	FACTOR LEVEL a_i	b_j	Y_m	MEANS
a_2	b_5	Y_1	1.48	a_1	b_6	Y_7	4.25
a_1	b_5	Y_2	1.65	a_1	b_4	Y_8	4.81
a_2	b_6	Y_3	2.90	a_2	b_4	Y_9	4.88
a_2	b_1	Y_4	3.09	a_2	b_2	Y_{10}	5.10
a_1	b_1	Y_5	3.52	a_1	b_3	Y_{11}	6.03
a_2	b_3	Y_6	4.19	a_1	b_2	Y_{12}	6.20

P	LSR	P	LSR
2	0.86	8	1.00
3	0.91	9	1.01
4	0.94	10	1.02
5	0.96	11	1.03
6	0.97	12	1.03
7	0.99		

6. Table E.3 shows the comparison test results on means of AB interaction in Table E.1. Table E.3 was produced through the execution of the Duncan program.

Tables of each of the other interactions and results of the comparison test on each of means of interaction are shown in the following pages.

TABLE E.3 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	6.20	1.48	4.72	1.02	*
12 vs 2	6.20	1.56	4.55	1.02	*
12 vs 3	6.20	2.90	3.30	1.01	*
12 vs 4	6.20	3.09	3.11	1.00	*
12 vs 5	6.20	3.52	2.68	0.99	*
12 vs 6	6.20	4.19	2.01	0.98	*
12 vs 7	6.20	4.25	1.95	0.97	*
12 vs 8	6.20	4.81	1.39	0.95	*
12 vs 9	6.20	4.88	1.32	0.93	*
12 vs 10	6.20	5.10	1.10	0.90	*
12 vs 11	6.20	6.03	0.17	0.85	
11 vs 1	6.03	1.48	4.55	1.02	*
11 vs 2	6.03	1.65	4.38	1.01	*
11 vs 3	6.03	2.90	3.13	1.00	*
11 vs 4	6.03	3.09	2.94	0.99	*
11 vs 5	6.03	3.52	2.51	0.98	*
11 vs 6	6.03	4.19	1.84	0.97	*
11 vs 7	6.03	4.25	1.78	0.95	*
11 vs 8	6.03	4.81	1.22	0.93	*
11 vs 9	6.03	4.88	1.15	0.90	*
11 vs 10	6.03	5.10	0.93	0.85	*
10 vs 1	5.10	1.48	3.62	1.01	*
10 vs 2	5.10	1.65	3.45	1.00	*
10 vs 3	5.10	2.90	2.20	0.99	*
10 VS 4	5.10	3.09	2.01	0.98	*
10 vs 5	5.10	3.52	1.58	0.97	*
10 vs 6	5.10	4.19	0.91	0.95	
10 vs 7	5.10	4.25	0.85	0.93	
10 vs 8	5.10	4.81	0.29	0.90	
10 vs 9	5.10	4.88	0.22	0.85	
9 vs 1	4.88	1.48	3.40	1.00	*
9 vs 2	4.88	1.65	3.23	0.99	*
9 vs 3	4.88	2.90	1.98	0.98	*
9 vs 4	4.88	3.09	1.79	0.97	*
9 vs 5	4.88	3.52	1.36	0.95	*
9 vs 6	4.88	4.19	0.69	0.93	
9 vs 7	4.88	4.25	0.63	0.90	
9 vs 8	4.88	4.81	0.07	0.85	
8 vs 1	4.81	1.48	3.33	0.99	*
8 vs 2	4.81	1.65	3.16	0.98	*
8 vs 3	4.81	2.90	1.91	0.97	*
8 vs 4	4.81	3.09	1.72	0.95	*
8 vs 5	4.81	3.52	1.29	0.93	*

TABLE E.3 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	4.81	4.19	0.62	0.90	
8 vs 7	4.81	4.25	0.56	0.85	
7 vs 1	4.25	1.48	2.77	0.98	*
7 vs 2	4.25	1.65	2.60	0.97	*
7 vs 3	4.25	2.90	1.35	0.95	*
7 vs 4	4.25	3.09	1.16	0.93	*
7 vs 5	4.25	3.52	0.73	0.90	
7 vs 6	4.25	4.19	0.06	0.85	
6 vs 1	4.19	1.48	2.71	0.97	*
6 vs 2	4.19	1.65	2.54	0.95	*
6 vs 3	4.19	2.90	1.29	0.93	*
6 vs 4	4.19	3.09	1.10	0.90	*
6 vs 5	4.19	3.52	0.67	0.85	
5 vs 1	3.52	1.48	2.04	0.95	*
5 vs 2	3.52	1.65	1.87	0.93	*
5 vs 3	3.52	2.90	0.62	0.90	
5 vs 4	3.52	3.09	0.43	0.85	
4 vs 1	3.09	1.48	1.61	0.93	*
4 vs 2	3.09	1.65	1.44	0.90	*
4 vs 3	3.09	2.90	0.19	0.85	
3 vs 1	2.90	1.48	1.42	0.90	*
3 vs 2	2.90	1.65	1.25	0.85	*
2 vs 1	1.65	1.48	0.17	0.85	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.4 MEANS OF INTERACTION BETWEEN FACTORS B AND C FOR RMS OF TARDINESS

FACTOR b_j	LEVEL c_k	MEANS	FACTOR b_j	LEVEL c_k	MEANS
b_1	c_1	3.85	b_1	c_2	2.76
b_2	c_1	7.07	b_2	c_2	4.23
b_3	c_1	6.32	b_3	c_2	3.89
b_4	c_1	4.86	b_4	c_2	4.84
b_5	c_1	1.66	b_5	c_2	1.46
b_6	c_1	3.87	b_6	c_2	3.30

$j = 1, 2, \ldots\ldots 6$

$k = 1, 2$

The comparison test of the means in Table E.4 is shown in Table E.5

TABLE E.5 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSr	SIGN
12 vs 1	7.07	1.46	5.61	1.02	*
12 vs 2	7.07	1.66	5.41	1.02	*
12 vs 3	7.07	2.76	4.31	1.01	*
12 vs 4	7.07	3.30	3.77	1.00	*
12 vs 5	7.07	3.85	3.22	0.99	*
12 vs 6	7.07	3.87	3.20	0.98	*
12 vs 7	7.07	3.89	3.18	0.97	*
12 vs 8	7.07	4.23	2.84	0.95	*
12 vs 9	7.07	4.84	2.23	0.93	*
12 vs 10	7.07	4.86	2.21	0.90	*
12 vs 11	7.07	6.32	0.75	0.85	
11 vs 1	6.32	1.46	4.86	1.02	*
11 vs 2	6.32	1.66	4.66	1.01	*
11 vs 3	6.32	2.76	3.56	1.00	*
11 vs 4	6.32	3.30	3.02	0.99	*
11 vs 5	6.32	3.85	2.47	0.98	*
11 vs 6	6.32	3.87	2.45	0.97	*
11 vs 7	6.32	3.89	2.43	0.95	*
11 vs 8	6.32	4.23	2.09	0.93	*
11 vs 9	6.32	4.84	1.48	0.90	*
11 vs 10	6.32	4.86	1.46	0.85	*
10 vs 1	4.86	1.46	3.40	1.01	*
10 vs 2	4.86	1.66	3.20	1.00	*
10 vs 3	4.86	2.76	2.10	0.99	*
10 vs 4	4.86	3.30	1.56	0.98	*
10 vs 5	4.86	3.85	1.01	0.97	*
10 vs 6	4.86	3.87	0.99	0.95	*
10 vs 7	4.86	3.89	0.97	0.93	*
10 vs 8	4.86	4.23	0.63	0.90	
10 vs 9	4.86	4.84	0.02	0.85	
9 vs 1	4.84	1.46	3.38	1.00	*
9 vs 2	4.84	1.66	3.18	0.99	*
9 vs 3	4.84	2.76	2.08	0.98	*
9 vs 4	4.84	3.30	1.54	0.97	*
9 vs 5	4.84	3.85	0.99	0.95	*
9 vs 6	4.84	3.87	0.97	0.93	*
9 vs 7	4.84	3.89	0.95	0.90	*
9 vs 8	4.84	4.23	0.61	0.85	
8 vs 1	4.23	1.46	2.77	0.99	*
8 vs 2	4.23	1.66	2.57	0.98	*
8 vs 3	4.23	2.76	1.47	0.97	*
8 vs 4	4.23	3.30	0.93	0.95	
8 vs 5	4.23	3.85	0.38	0.93	

TABLE E.5 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	4.23	3.87	0.36	0.90	
8 vs 7	4.23	3.89	0.34	0.85	
7 vs 1	3.89	1.46	2.43	0.98	*
7 vs 2	3.89	1.66	2.23	0.97	*
7 vs 3	3.89	2.76	1.13	0.95	*
7 vs 4	3.89	3.30	0.59	0.93	
7 vs 5	3.89	3.85	0.04	0.90	
7 vs 6	3.89	3.87	0.02	0.85	
6 vs 1	3.87	1.46	2.41	0.97	*
6 vs 2	3.87	1.66	2.21	0.95	*
6 vs 3	3.87	2.76	1.11	0.93	*
6 vs 4	3.87	3.30	0.57	0.90	
6 vs 5	3.87	3.85	0.02	0.85	
5 vs 1	3.85	1.46	2.39	0.95	*
5 vs 2	3.85	1.66	2.19	0.93	*
5 vs 3	3.85	2.76	1.09	0.90	*
5 vs 4	3.85	3.30	0.55	0.85	
4 vs 1	3.30	1.46	1.84	0.93	*
4 vs 2	3.30	1.66	1.64	0.90	*
4 vs 3	3.30	2.76	0.54	0.85	
3 vs 1	2.76	1.46	1.30	0.90	*
3 vs 2	2.76	1.66	1.10	0.85	*
2 vs 1	1.66	1.46	0.20	0.85	

* = Significant at the 0.05 level
LSR = Least significant range

TABLE E.6 MEANS OF INTERACTION BETWEEN FACTORS B AND D FOR RMS OF TARDINESS

FACTOR LEVEL		MEANS	FACTOR LEVEL		MEANS
b_j	d_l		b_j	d_l	
b_1	d_1	3.34	b_1	d_2	3.27
b_2	d_1	6.83	b_2	d_2	4.47
b_3	d_1	6.09	b_3	d_2	4.12
b_4	d_1	5.17	b_4	d_2	4.52
b_5	d_1	1.51	b_5	d_2	1.62
b_6	d_1	3.53	b_6	d_2	3.64

$j = 1, 2, \ldots..6$

$l = 1, 2$

The comparison test of the means in Table E.6 is shown in Table E.7.

TABLE E.7 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND D (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	6.83	1.51	5.32	1.02	*
12 vs 2	6.83	1.62	5.21	1.02	*
12 vs 3	6.83	3.27	3.56	1.01	*
12 vs 4	6.83	3.34	3.49	1.00	*
12 vs 5	6.83	3.53	3.30	0.99	*
12 vs 6	6.83	3.64	3.19	0.98	*
12 vs 7	6.83	4.12	2.71	0.97	*
12 vs 8	6.83	4.47	2.36	0.95	*
12 vs 9	6.83	4.52	2.31	0.93	*
12 vs 10	6.83	5.17	1.66	0.90	*
12 vs 11	6.83	6.09	0.74	0.85	
11 vs 1	6.09	1.51	4.58	1.02	*
11 vs 2	6.09	1.62	4.47	1.01	*
11 vs 3	6.09	3.27	2.82	1.00	*
11 vs 4	6.09	3.34	2.75	0.99	*
11 vs 5	6.09	3.53	2.56	0.98	*
11 vs 6	6.09	3.64	2.45	0.97	*
11 vs 7	6.09	4.12	1.97	0.95	*
11 vs 8	6.09	4.47	1.62	0.93	*
11 vs 9	6.09	4.52	1.57	0.90	*
11 vs 10	6.09	5.17	0.92	0.85	*
10 vs 1	5.17	1.51	3.66	1.01	*
10 vs 2	5.17	1.62	3.55	1.00	*
10 vs 3	5.17	3.27	1.90	0.99	*
10 vs 4	5.17	3.34	1.83	0.98	*
10 vs 5	5.17	3.53	1.64	0.97	*
10 vs 6	5.17	3.64	1.53	0.95	*
10 vs 7	5.17	4.12	1.05	0.93	*
10 vs 8	5.17	4.47	0.70	0.90	
10 vs 9	5.17	4.52	0.65	0.85	
9 vs 1	4.52	1.51	3.01	1.00	*
9 vs 2	4.52	1.62	2.90	0.99	*
9 vs 3	4.52	3.27	1.25	0.98	*
9 vs 4	4.52	3.34	1.18	0.97	*
9 vs 5	4.52	3.53	0.99	0.95	*
9 vs 6	4.52	3.64	0.88	0.93	
9 vs 7	4.52	4.12	0.40	0.90	
9 vs 8	4.52	4.47	0.05	0.85	
8 vs 1	4.47	1.51	2.96	0.99	*
8 vs 2	4.47	1.62	2.85	0.98	*
8 vs 3	4.47	3.27	1.20	0.97	*
8 vs 4	4.47	3.34	1.13	0.95	*
8 vs 5	4.47	3.53	0.94	0.93	*

TABLE E.7 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	4.47	3.64	0.83	0.90	
8 vs 7	4.47	4.12	0.35	0.85	
7 vs 1	4.12	1.51	2.61	0.98	*
7 vs 2	4.12	1.62	2.50	0.97	*
7 vs 3	4.12	3.27	0.85	0.95	
7 vs 4	4.12	3.34	0.78	0.93	
7 vs 5	4.12	3.53	0.59	0.90	
7 vs 6	4.12	3.64	0.48	0.85	
6 vs 1	3.64	1.51	2.13	0.97	*
6 vs 2	3.64	1.62	2.02	0.95	*
6 vs 3	3.64	3.27	0.37	0.93	
6 vs 4	3.64	3.34	0.30	0.90	
6 vs 5	3.64	3.53	0.11	0.85	
5 vs 1	3.53	1.51	2.02	0.95	*
5 vs 2	3.53	1.62	1.91	0.93	*
5 vs 3	3.53	3.27	0.26	0.90	
5 vs 4	3.53	3.34	0.19	0.85	
4 vs 1	3.34	1.51	1.83	0.93	*
4 vs 2	3.34	1.62	1.72	0.90	*
4 vs 3	3.34	3.27	0.07	0.85	
3 vs 1	3.27	1.51	1.76	0.90	*
3 vs 2	3.27	1.62	1.65	0.85	*
2 vs 1	1.62	1.51	0.11	0.85	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.8 MEANS OF INTERACTION BETWEEN FACTORS C AND D (FOR RMS OF TARDINESS)

FACTOR	LEVEL	MEANS	FACTOR	LEVEL	MEANS
c_k	d_l		c_k	d_l	
c_1	d_1	5.27	c_1	d_2	3.94
c_2	d_1	3.55	c_2	d_2	3.28

$k = 1, 2$

$l = 1, 2$

The comparison test of the means in Table E.8 is shown in Table E.9.

TABLE E.9 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS C AND D (FOR MEANS OF RMS OF TARDINESS

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	5.27	3.28	1.99	0.54	*
4 vs 2	5.27	3.55	1.72	0.52	*
4 vs 3	5.27	3.94	1.33	0.49	*
3 vs 1	3.94	3.28	0.66	0.52	*
3 vs 2	3.94	3.55	0.39	0.49	
2 vs 1	3.55	3.28	0.27	0.49	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.10 MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (FOR RMS OF TARDINESS)

FACTOR LEVEL			MEANS	FACTOR LEVEL			MEANS
a_i	b_j	b_k		a_i	b_j	c_k	
a_1	b_1	c_1	4.19	a_2	b_1	c_1	3.14
a_1	b_2	c_1	9.12	a_2	b_2	c_1	5.03
a_1	b_3	c_1	7.06	a_2	b_3	c_1	5.58
a_1	b_4	c_1	4.58	a_2	b_4	c_1	5.14
a_1	b_5	c_1	1.70	a_2	b_5	c_1	1.63
a_1	b_6	c_1	4.61	a_2	b_6	c_1	3.13
a_1	b_1	c_2	2.86	a_2	b_1	c_2	2.67
a_1	b_2	c_2	3.29	a_2	b_2	c_2	5.17
a_1	b_3	c_2	5.00	a_2	b_3	c_2	2.79
a_1	b_4	c_2	5.05	a_2	b_4	c_2	4.63
a_1	b_5	c_2	1.60	a_2	b_5	c_2	1.33
a_1	b_6	c_2	3.90	a_2	b_6	c_2	2.70

The comparison test of the means in Table E.10 is shown in Table E.11.

TABLE E.11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B, AND C (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	9.12	1.33	7.79	1.52	*
24 vs 2	9.12	1.60	7.52	1.52	*
24 vs 3	9.12	1.63	7.49	1.51	*
24 vs 4	9.12	1.70	7.42	1.51	*
24 vs 5	9.12	2.67	6.45	1.51	*
24 vs 6	9.12	2.70	6.42	1.50	*
24 vs 7	9.12	2.79	6.33	1.49	*
24 vs 8	9.12	2.86	6.26	1.49	*
24 vs 9	9.12	3.13	5.99	1.48	*
24 vs 10	9.12	3.14	5.98	1.47	*
24 vs 11	9.12	3.29	5.83	1.46	*
24 vs 12	9.12	3.90	5.22	1.45	*
24 vs 13	9.12	4.19	4.93	1.45	*
24 vs 14	9.12	4.58	4.54	1.44	*
24 vs 15	9.12	4.61	4.51	1.43	*
24 vs 16	9.12	4.63	4.49	1.42	*
24 vs 17	9.12	5.00	4.12	1.40	*
24 vs 18	9.12	5.03	4.09	1.39	*
24 vs 19	9.12	5.05	4.07	1.37	*
24 vs 20	9.12	5.14	3.98	1.34	*
24 vs 21	9.12	5.17	3.95	1.31	*
24 vs 22	9.12	5.58	3.54	1.27	*
24 vs 23	9.12	7.06	2.06	1.20	*
23 vs 1	7.06	1.33	5.73	1.52	*
23 vs 2	7.06	1.60	5.46	1.51	*
23 vs 3	7.06	1.63	5.43	1.51	*
23 vs 4	7.06	1.70	5.36	1.51	*
23 vs 5	7.06	2.67	4.39	1.50	*
23 vs 6	7.06	2.70	4.36	1.49	*
23 vs 7	7.06	2.79	4.27	1.49	*
23 vs 8	7.06	2.86	4.20	1.48	*
23 vs 9	7.06	3.13	3.93	1.47	*
23 vs 10	7.06	3.14	3.92	1.46	*
23 vs 11	7.06	3.29	3.77	1.45	*
23 vs 12	7.06	3.90	3.16	1.45	*
23 vs 13	7.06	4.19	2.87	1.44	*
23 vs 14	7.06	4.58	2.48	1.43	*
23 vs 15	7.06	4.61	2.45	1.42	*
23 vs 16	7.06	4.63	2.43	1.40	*
23 vs 17	7.06	5.00	2.06	1.39	*
23 vs 18	7.06	5.03	2.03	1.37	*
23 vs 19	7.06	5.05	2.01	1.34	*
23 vs 20	7.06	5.14	1.92	1.31	*

TABLE E.11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B, AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 21	7.06	5.17	1.89	1.27	*
23 vs 22	7.06	5.58	1.48	1.20	*
22 vs 1	5.58	1.33	4.25	1.51	*
22 vs 2	5.58	1.60	3.98	1.51	*
22 vs 3	5.58	1.63	3.95	1.51	*
22 vs 4	5.58	1.70	3.88	1.50	*
22 vs 5	5.58	2.67	2.91	1.49	*
22 vs 6	5.58	2.70	2.88	1.49	*
22 vs 7	5.58	2.79	2.79	1.48	*
22 vs 8	5.58	2.86	2.72	1.47	*
22 vs 9	5.58	3.13	2.45	1.46	*
22 vs 10	5.58	3.14	2.44	1.45	*
22 vs 11	5.58	3.29	2.29	1.45	*
22 vs 12	5.58	3.90	1.68	1.44	*
22 vs 13	5.58	4.19	1.39	1.43	
22 vs 14	5.58	4.58	1.00	1.42	
22 vs 15	5.58	4.61	0.97	1.40	
22 vs 16	5.58	4.63	0.95	1.39	
22 vs 17	5.58	5.00	0.58	1.37	
22 vs 18	5.58	5.03	0.55	1.34	
22 vs 19	5.58	5.05	0.53	1.31	
22 vs 20	5.58	5.14	0.44	1.27	
22 vs 21	5.58	5.17	0.41	1.20	
21 vs 1	5.17	1.33	3.84	1.51	*
21 vs 2	5.17	1.60	3.57	1.51	*
21 vs 3	5.17	1.63	3.54	1.50	*
21 vs 4	5.17	1.70	3.47	1.49	*
21 vs 5	5.17	2.67	2.50	1.49	*
21 vs 6	5.17	2.70	2.47	1.48	*
21 vs 7	5.17	2.79	2.38	1.47	*
21 vs 8	5.17	2.86	2.31	1.46	*
21 vs 9	5.17	3.13	2.04	1.45	*
21 vs 10	5.17	3.14	2.03	1.45	*
21 vs 11	5.17	3.29	1.88	1.44	*
21 vs 12	5.17	3.90	1.27	1.43	
21 vs 13	5.17	4.19	0.98	1.42	
21 vs 14	5.17	4.58	0.59	1.40	
21 vs 15	5.17	4.61	0.56	1.39	
21 vs 16	5.17	4.63	0.54	1.37	
21 vs 17	5.17	5.00	0.17	1.34	
21 vs 18	5.17	5.03	0.14	1.31	
21 vs 19	5.17	5.05	0.12	1.27	
21 vs 20	5.17	5.14	0.03	1.20	
20 vs 1	5.14	1.33	3.81	1.51	*

TABLE E.11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	(Ym)	(Yn)	DIFFERENCE	LSR	SIGN
20 vs 2	5.14	1.60	3.54	1.50	*
20 vs 3	5.14	1.63	3.51	1.49	*
20 vs 4	5.14	1.70	3.44	1.49	*
20 vs 5	5.14	2.67	2.47	1.48	*
20 vs 6	5.14	2.70	2.44	1.47	*
20 vs 7	5.14	2.79	2.35	1.46	*
20 vs 8	5.14	2.86	2.28	1.45	*
20 vs 9	5.14	3.13	2.01	1.45	*
20 vs 10	5.14	3.14	2.00	1.44	*
20 vs 11	5.14	3.29	1.85	1.43	*
20 vs 12	5.14	3.90	1.24	1.42	
20 vs 13	5.14	4.19	0.95	1.40	
20 vs 14	5.14	4.58	0.56	1.39	
20 vs 15	5.14	4.61	0.53	1.37	
20 vs 16	5.14	4.63	0.51	1.34	
20 vs 17	5.14	5.00	0.14	1.31	
20 vs 18	5.14	5.03	0.11	1.27	
20 vs 19	5.14	5.05	0.09	1.20	
19 vs 1	5.05	1.33	3.72	1.50	*
19 vs 2	5.05	1.60	3.45	1.49	*
19 vs 3	5.05	1.63	3.42	1.49	*
19 vs 4	5.05	1.70	3.35	1.48	*
19 vs 5	5.05	2.67	2.38	1.47	*
19 vs 6	5.05	2.70	2.35	1.46	*
19 vs 7	5.05	2.79	2.26	1.45	*
19 vs 8	5.05	2.86	2.19	1.45	*
19 vs 9	5.05	3.13	1.92	1.44	*
19 vs 10	5.05	3.14	1.91	1.43	*
19 vs 11	5.05	3.29	1.76	1.42	*
19 vs 12	5.05	3.90	1.15	1.40	
19 vs 13	5.05	4.19	0.86	1.39	
19 vs 14	5.05	4.58	0.47	1.37	
19 vs 15	5.05	4.61	0.44	1.34	
19 vs 16	5.05	4.63	0.42	1.31	
19 vs 17	5.05	5.00	0.05	1.27	
19 vs 18	5.05	5.03	0.02	1.20	
18 vs 1	5.03	1.33	3.70	1.49	*
18 vs 2	5.03	1.60	3.43	1.49	*
18 vs 3	5.03	1.63	3.40	1.48	*
18 vs 4	5.03	1.70	3.33	1.47	*
18 vs 5	5.03	2.67	2.36	1.46	*
18 vs 6	5.03	2.70	2.33	1.45	*
18 vs 7	5.03	2.79	2.24	1.45	*
18 vs 8	5.03	2.86	2.17	1.44	*

TABLE E.11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	5.03	3.13	1.90	1.43	*
18 vs 10	5.03	3.14	1.89	1.42	*
18 vs 11	5.03	3.29	1.74	1.40	*
18 vs 12	5.03	3.90	1.13	1.39	
18 vs 13	5.03	4.19	0.84	1.37	
18 vs 14	5.03	4.58	0.45	1.34	
18 vs 15	5.03	4.61	0.42	1.31	
18 vs 16	5.03	4.63	0.40	1.27	
18 vs 17	5.03	5.00	0.03	1.20	
17 vs 1	5.00	1.33	3.67	1.49	*
17 vs 2	5.00	1.60	3.40	1.48	*
17 vs 3	5.00	1.63	3.37	1.47	*
17 vs 4	5.00	1.70	3.30	1.46	*
17 vs 5	5.00	2.67	2.33	1.45	*
17 vs 6	5.00	2.70	2.30	1.45	*
17 vs 7	5.00	2.79	2.21	1.44	*
17 vs 8	5.00	2.86	2.14	1.43	*
17 vs 9	5.00	3.13	1.87	1.42	*
17 vs 10	5.00	3.14	1.86	1.40	*
17 vs 11	5.00	3.29	1.71	1.39	*
17 vs 12	5.00	3.90	1.10	1.37	
17 vs 13	5.00	4.19	0.81	1.34	
17 vs 14	5.00	4.58	0.42	1.31	
17 vs 15	5.00	4.61	0.39	1.27	
17 vs 16	5.00	4.63	0.37	1.20	
16 vs 1	4.63	1.33	3.30	1.48	*
16 vs 2	4.63	1.60	3.03	1.47	*
16 vs 3	4.63	1.63	3.00	1.46	*
16 vs 4	4.63	1.70	2.93	1.45	*
16 vs 5	4.63	2.67	1.96	1.45	*
16 vs 6	4.63	2.70	1.93	1.44	*
16 vs 7	4.63	2.79	1.84	1.43	*
16 vs 8	4.63	2.86	1.77	1.42	*
16 vs 9	4.63	3.13	1.50	1.40	*
16 vs 10	4.63	3.14	1.49	1.39	*
16 vs 11	4.63	3.29	1.34	1.37	
16 vs 12	4.63	3.90	0.73	1.34	
16 vs 13	4.63	4.19	0.44	1.31	
16 vs 14	4.63	4.58	0.05	1.27	
16 vs 15	4.63	4.61	0.02	1.20	
15 vs 1	4.61	1.33	3.28	1.47	*
15 vs 2	4.61	1.60	3.01	1.46	*
15 vs 3	4.61	1.63	2.98	1.45	*
15 VS 4	4.61	1.70	2.91	1.45	*

TABLE E.11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	4.61	2.67	1.94	1.44	*
15 vs 6	4.61	2.70	1.91	1.43	*
15 vs 7	4.61	2.79	1.82	1.42	*
15 vs 8	4.61	2.86	1.75	1.40	*
15 vs 9	4.61	3.13	1.48	1.39	*
15 vs 10	4.61	3.14	1.47	1.37	*
15 vs 11	4.61	3.29	1.32	1.34	
15 vs 12	4.61	3.90	0.71	1.31	
15 vs 13	4.61	4.19	0.42	1.27	
15 vs 14	4.16	4.58	0.03	1.20	
14 vs 1	4.58	1.33	3.25	1.46	*
14 vs 2	4.58	1.60	2.98	1.45	*
14 vs 3	4.58	1.63	2.95	1.45	*
14 vs 4	4.58	1.70	2.88	1.44	*
14 vs 5	4.58	2.67	1.91	1.43	*
14 vs 6	4.58	2.70	1.88	1.42	*
14 vs 7	4.58	2.79	1.79	1.40	*
14 vs 8	4.58	2.86	1.72	1.39	*
14 vs 9	4.58	3.13	1.45	1.37	*
14 vs 10	4.58	3.14	1.44	1.34	*
14 vs 11	4.58	3.29	1.29	1.31	
14 vs 12	4.58	3.90	0.68	1.27	
14 vs 13	4.58	4.19	0.39	1.20	
13 vs 1	4.19	1.33	2.86	1.45	*
13 vs 2	4.19	1.60	2.59	1.45	*
13 vs 3	4.19	1.63	2.56	1.44	*
13 vs 4	4.19	1.70	2.49	1.43	*
13 vs 5	4.19	2.67	1.52	1.42	*
13 vs 6	4.19	2.70	1.49	1.40	*
13 vs 7	4.19	2.79	1.40	1.39	*
13 vs 8	4.19	2.86	1.33	1.37	
13 vs 9	4.19	3.13	1.06	1.34	
13 vs 10	4.19	3.14	1.05	1.31	
13 vs 11	4.19	3.29	0.90	1.27	
13 vs 12	4.19	3.90	0.29	1.20	
12 vs 1	3.90	1.33	2.57	1.45	*
12 vs 2	3.90	1.60	2.30	1.44	*
12 vs 3	3.90	1.63	2.27	1.43	*
12 vs 4	3.90	1.70	2.20	1.42	*
12 vs 5	3.90	2.67	1.23	1.40	
12 vs 6	3.90	2.70	1.20	1.39	
12 vs 7	3.90	2.79	1.11	1.37	
12 vs 8	3.90	2.86	1.04	1.34	
12 vs 9	3.90	3.13	0.77	1.31	

TABLE E. 11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	3.90	3.14	0.76	1.27	
12 vs 11	3.90	3.29	0.61	1.20	
11 vs 1	3.29	1.33	1.96	1.44	*
11 vs 2	3.29	1.60	1.69	1.43	*
11 vs 3	3.29	1.63	1.66	1.42	*
11 vs 4	3.29	1.70	1.59	1.40	*
11 vs 5	3.29	2.67	0.62	1.39	
11 vs 6	3.29	2.70	0.59	1.37	
11 vs 7	3.29	2.79	0.50	1.34	
11 vs 8	3.29	2.86	0.43	1.31	
11 vs 9	3.29	3.13	0.16	1.27	
11 vs 10	3.29	3.14	0.15	1.20	
10 vs 1	3.14	1.33	1.81	1.43	*
10 vs 2	3.14	1.60	1.54	1.42	*
10 vs 3	3.14	1.63	1.51	1.40	*
10 vs 4	3.14	1.70	1.44	1.39	*
10 vs 5	3.14	2.67	0.47	1.37	
10 vs 6	3.14	2.70	0.44	1.34	
10 vs 7	3.14	2.79	0.35	1.31	
10 vs 8	3.14	2.86	0.28	1.27	
10 vs 9	3.14	3.13	0.01	1.20	
9 vs 1	3.13	1.33	1.80	1.42	*
9 vs 2	3.13	1.60	1.53	1.40	*
9 vs 3	3.13	1.63	1.50	1.39	*
9 vs 4	3.13	1.70	1.43	1.37	*
9 vs 5	3.13	2.67	0.46	1.34	
9 vs 6	3.13	2.70	0.43	1.31	
9 vs 7	3.13	2.79	0.34	1.27	
9 vs 8	3.13	2.86	0.27	1.20	
8 vs 1	2.86	1.33	1.53	1.40	*
8 vs 2	2.86	1.60	1.26	1.39	
8 vs 3	2.86	1.63	1.23	1.37	
8 vs 4	2.86	1.70	1.16	1.34	
8 vs 5	2.86	2.67	0.19	1.31	
8 vs 6	2.86	2.70	0.16	1.27	
8 vs 7	2.86	2.79	0.07	1.20	
7 vs 1	2.79	1.33	1.46	1.39	*
7 vs 2	2.79	1.60	1.19	1.37	
7 vs 3	2.79	1.63	1.16	1.34	
7 vs 4	2.79	1.70	1.09	1.31	
7 vs 5	2.79	2.67	0.12	1.27	
7 vs 6	2.79	2.70	0.09	1.20	
6 vs 1	2.70	1.33	1.37	1.37	*
6 vs 2	2.70	1.60	1.10	1.34	

TABLE E 11 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	2.70	1.63	1.07	1.31	
6 vs 4	2.70	1.70	1.00	1.27	
6 vs 5	2.70	2.67	0.03	1.20	
5 vs 1	2.67	1.33	1.34	1.34	
5 vs 2	2.67	1.60	1.07	1.31	
5 vs 3	2.67	1.63	1.04	1.27	
5 vs 4	2.67	1.70	0.97	1.20	
4 vs 1	1.70	1.33	0.37	1.31	
4 vs 2	1.70	1.60	0.10	1.27	
4 vs 3	1.70	1.63	0.07	1.20	
3 vs 1	1.63	1.33	0.30	1.27	
3 vs 2	1.63	1.60	0.03	1.20	
2 vs 1	1.60	1.33	0.27	1.20	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.12 MEANS OF INTERACTION BETWEEN FACTORS A, B AND D FOR RMS OF TARDINESS

FACTOR LEVEL			MEANS	FACTOR LEVEL			MEANS
a_i	b_j	c_1		a_1	b_j	c_1	
a_1	b_1	d_1	3.57	a_2	b_1	d_1	3.11
a_1	b_2	d_1	6.62	a_2	b_2	d_1	7.04
a_1	b_3	d_1	7.17	a_2	b_3	d_1	5.01
a_1	b_4	d_1	5.43	a_2	b_4	d_1	4.92
a_1	b_5	d_1	1.66	a_2	b_5	d_1	1.36
a_1	b_6	d_1	4.19	a_2	b_6	d_1	2.87
a_1	b_1	d_2	3.48	a_2	b_1	d_2	3.07
a_1	b_2	d_2	5.79	a_2	b_2	d_2	2.10
a_1	b_3	d_2	4.89	a_2	b_3	d_2	3.36
a_1	b_4	d_2	4.20	a_2	b_4	d_2	4.85
a_1	b_5	d_2	1.64	a_2	b_5	d_2	1.42
a_1	b_6	d_2	4.32	a_2	b_6	d_2	2.96

TABLE E.13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	7.17	1.36	5.81	1.52	*
24 vs 2	7.17	1.42	5.75	1.52	*
24 vs 3	7.17	1.64	5.53	1.51	*
24 vs 4	7.17	1.66	5.51	1.51	*
24 vs 5	7.17	2.10	5.07	1.51	*
24 vs 6	7.17	2.87	4.30	1.50	*
24 vs 7	7.17	2.96	4.21	1.49	*
24 vs 8	7.17	3.07	4.10	1.49	*
24 vs 9	7.17	3.11	4.06	1.48	*
24 vs 10	7.17	3.36	3.81	1.47	*
24 vs 11	7.17	3.48	3.69	1.46	*
24 vs 12	7.17	3.57	3.60	1.45	*
24 vs 13	7.17	4.19	2.98	1.45	*
24 vs 14	7.17	4.20	2.97	1.44	*
24 vs 15	7.17	4.32	2.85	1.43	*
24 vs 16	7.17	4.85	2.32	1.42	*
24 vs 17	7.17	4.89	2.28	1.40	*
24 vs 18	7.17	4.92	2.25	1.39	*
24 vs 19	7.17	5.01	2.16	1.37	*
24 vs 20	7.17	5.43	1.74	1.34	*
24 vs 21	7.17	5.79	1.38	1.31	*
24 vs 22	7.17	6.62	0.55	1.27	
24 vs 23	7.17	7.04	0.13	1.20	
23 vs 1	7.04	1.36	5.68	1.52	*
23 vs 2	7.04	1.42	5.62	1.51	*
23 vs 3	7.04	1.64	5.40	1.51	*
23 vs 4	7.04	1.66	5.38	1.51	*
23 vs 5	7.04	2.10	4.94	1.50	*
23 vs 6	7.04	2.87	4.17	1.49	*
23 vs 7	7.04	2.96	4.08	1.49	*
23 vs 8	7.04	3.07	3.97	1.48	*
23 vs 9	7.04	3.11	3.93	1.47	*
23 vs 10	7.04	3.36	3.68	1.46	*
23 vs 11	7.04	3.48	3.56	1.45	*
23 vs 12	7.04	3.57	3.47	1.45	*
23 vs 13	7.04	4.19	2.85	1.44	*
23 vs 14	7.04	4.20	2.84	1.43	*
23 vs 15	7.04	4.32	2.72	1.42	*
23 vs 16	7.04	4.85	2.19	1.40	*
23 vs 17	7.04	4.89	2.15	1.39	*
23 vs 18	7.04	4.92	2.12	1.37	*
23 vs 19	7.04	5.01	2.03	1.34	*
23 vs 20	7.04	5.43	1.61	1.31	*

TABLE E.13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 21	7.04	5.79	1.25	1.27	
23 vs 22	7.04	6.62	0.42	1.20	
22 vs 1	6.62	1.36	5.26	1.51	*
22 vs 2	6.62	1.42	5.20	1.51	*
22 vs 3	6.62	1.64	4.98	1.51	*
22 vs 4	6.62	1.66	4.96	1.50	*
22 vs 5	6.62	2.10	4.52	1.49	*
22 vs 6	6.62	2.87	3.75	1.49	*
22 vs 7	6.62	2.96	3.66	1.48	*
22 vs 8	6.62	3.07	3.55	1.47	*
22 vs 9	6.62	3.11	3.51	1.46	*
22 vs 10	6.62	3.36	3.26	1.45	*
22 vs 11	6.62	3.48	3.14	1.45	*
22 vs 12	6.62	3.57	3.05	1.44	*
22 vs 13	6.62	4.19	2.43	1.43	*
22 vs 14	6.62	4.20	2.42	1.42	*
22 vs 15	6.62	4.32	2.30	1.40	*
22 vs 16	6.62	4.85	1.77	1.39	*
22 vs 17	6.62	4.89	1.73	1.37	*
22 vs 18	6.62	4.92	1.70	1.34	*
22 vs 19	6.62	5.01	1.61	1.31	*
22 vs 20	6.62	5.43	1.19	1.27	
22 vs 21	6.62	5.79	0.83	1.20	
21 vs 1	5.79	1.36	4.43	1.51	*
21 vs 2	5.79	1.42	4.37	1.51	*
21 vs 3	5.79	1.64	4.15	1.50	*
21 vs 4	5.79	1.66	4.13	1.49	*
21 vs 5	5.79	2.10	3.69	1.49	*
21 vs 6	5.79	2.87	2.92	1.48	*
21 vs 7	5.79	2.96	2.83	1.47	*
21 vs 8	5.79	3.07	2.72	1.46	*
21 vs 9	5.79	3.11	2.68	1.45	*
21 vs 10	5.79	3.36	2.43	1.45	*
21 vs 11	5.79	3.48	2.31	1.44	*
21 vs 12	5.79	3.57	2.22	1.43	*
21 vs 13	5.79	4.19	1.60	1.42	*
21 vs 14	5.79	4.20	1.59	1.40	*
21 vs 15	5.79	4.32	1.47	1.39	*
21 vs 16	5.79	4.85	0.94	1.37	
21 vs 17	5.79	4.89	0.90	1.34	
21 vs 18	5.79	4.92	0.87	1.31	
21 vs 19	5.79	5.01	0.78	1.27	
21 vs 21	5.79	5.43	0.36	1.20	
20 vs 1	5.43	1.36	4.07	1.51	*

TABLE E.13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B, AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	sign
20 vs 2	5.43	1.42	4.01	1.50	*
20 vs 3	5.43	1.64	3.79	1.49	*
20 vs 5	5.43	2.10	3.33	1.48	*
20 vs 6	5.43	2.87	2.56	1.47	*
20 vs 7	5.43	2.96	2.47	1.46	*
20 vs 8	5.43	3.07	2.36	1.45	*
20 vs 9	5.43	3.11	2.32	1.45	*
20 vs 10	5.43	3.36	2.07	1.44	*
20 vs 11	5.43	3.48	1.95	1.43	*
20 vs 12	5.43	3.57	1.86	1.42	*
20 vs 13	5.43	4.19	1.24	1.40	
20 vs 14	5.43	4.20	1.23	1.39	
20 vs 15	5.43	4.32	1.11	1.37	
20 vs 16	5.43	4.85	0.58	1.34	
20 vs 17	5.43	4.89	0.54	1.31	
20 vs 18	5.43	4.92	0.51	1.27	
20 vs 19	5.43	5.01	0.42	1.20	
19 vs 1	5.01	1.36	3.65	1.50	*
19 vs 2	5.01	1.42	3.59	1.49	*
19 vs 3	5.01	1.64	3.37	1.49	*
19 vs 4	5.01	1.66	3.35	1.48	*
19 vs 5	5.01	2.10	2.91	1.47	*
19 vs 6	5.01	2.87	2.14	1.46	*
19 vs 7	5.01	2.96	2.05	1.45	*
19 vs 8	5.01	3.07	1.94	1.45	*
19 vs 9	5.01	3.11	1.90	1.44	*
19 vs 10	5.01	3.36	1.65	1.43	*
19 vs 11	5.01	3.48	1.53	1.42	*
19 vs 12	5.01	3.57	1.44	1.40	*
19 vs 13	5.01	4.19	0.82	1.39	
19 vs 14	5.01	4.20	0.81	1.37	
19 vs 15	5.01	4.32	0.69	1.34	
19 vs 16	5.01	4.85	0.16	1.31	
19 vs 17	5.01	4.89	0.12	1.27	
19 vs 18	5.01	4.92	0.09	1.20	
18 vs 1	4.92	1.36	3.56	1.49	*
18 vs 2	4.92	1.42	3.50	1.49	*
18 vs 3	4.92	1.64	3.28	1.48	*
18 vs 4	4.92	1.66	3.26	1.47	*
18 vs 5	4.92	2.10	2.82	1.46	*
18 vs 6	4.92	2.87	2.05	1.45	*
18 vs 7	4.92	2.96	1.96	1.45	*
18 vs 8	4.92	3.07	1.85	1.44	*

TABLE E. 13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	4.92	3.11	1.81	1.43	*
18 vs 10	4.92	3.36	1.56	1.42	*
18 vs 11	4.92	3.48	1.44	1.40	*
18 vs 12	4.92	3.57	1.35	1.39	
18 vs 13	4.92	4.19	0.73	1.37	
18 vs 14	4.92	4.20	0.72	1.34	
18 vs 15	4.92	4.32	0.60	1.31	
18 vs 16	4.92	4.85	0.07	1.27	
18 vs 17	4.92	4.89	0.03	1.20	
17 vs 1	4.89	1.36	3.53	1.49	*
17 vs 2	4.89	1.42	3.47	1.48	*
17 vs 3	4.89	1.64	3.25	1.47	*
17 vs 4	4.89	1.66	3.23	1.46	*
17 vs 5	4.89	2.10	2.79	1.45	*
17 vs 6	4.89	2.87	2.02	1.45	*
17 vs 7	4.89	2.96	1.93	1.44	*
17 vs 8	4.89	3.07	1.82	1.43	*
17 vs 9	4.89	3.11	1.78	1.42	*
17 vs 10	4.89	3.36	1.53	1.40	*
17 vs 11	4.89	3.48	1.41	1.39	*
17 vs 12	4.89	3.57	1.32	1.37	
17 vs 13	4.89	4.19	0.70	1.34	
17 vs 14	4.89	4.20	0.69	1.31	
17 vs 15	4.89	4.32	0.57	1.27	
17 vs 16	4.89	4.85	0.04	1.20	
16 vs 1	4.85	1.36	3.49	1.48	*
16 vs 2	4.85	1.42	3.43	1.47	*
16 vs 3	4.85	1.64	3.21	1.46	*
16 vs 4	4.85	1.66	3.19	1.45	*
16 vs 5	4.85	2.10	2.75	1.45	*
16 vs 6	4.85	2.87	1.98	1.44	*
16 vs 7	4.85	2.96	1.89	1.43	*
16 vs 8	4.85	3.07	1.78	1.42	*
16 vs 9	4.85	3.11	1.74	1.40	*
16 vs 10	4.85	3.36	1.49	1.39	*
16 vs 11	4.85	3.48	1.37	1.37	*
16 vs 12	4.85	3.57	1.28	1.34	
16 vs 13	4.85	4.19	0.66	1.31	
16 vs 14	4.85	4.20	0.65	1.27	
16 vs 15	4.85	4.32	0.53	1.20	
15 vs 1	4.32	1.36	2.96	1.47	*
15 vs 2	4.32	1.42	2.90	1.46	*
15 vs 3	4.32	1.64	2.68	1.45	*
15 vs 4	4.32	1.66	2.66	1.45	*

TABLE E. 13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	4.32	2.10	2.22	1.44	*
15 vs 6	4.32	2.87	1.45	1.43	*
15 vs 7	4.32	2.96	1.36	1.42	
15 vs 8	4.32	3.07	1.25	1.40	
15 vs 9	4.32	3.11	1.21	1.39	
15 vs 10	4.32	3.36	0.96	1.37	
15 vs 11	4.32	3.48	0.84	1.34	
15 vs 12	4.32	3.57	0.75	1.31	
15 vs 13	4.32	4.19	0.13	1.27	
15 vs 14	4.32	4.20	0.12	1.20	
14 vs 1	4.20	1.36	2.84	1.46	*
14 vs 2	4.20	1.42	2.78	1.45	*
14 vs 3	4.20	1.64	2.56	1.45	*
14 vs 4	4.20	1.66	2.54	1.44	*
14 vs 5	4.20	2.10	2.10	1.43	*
14 vs 6	4.20	2.87	1.33	1.42	
14 vs 7	4.20	2.96	1.24	1.40	
14 vs 8	4.20	3.07	1.13	1.39	
14 vs 9	4.20	3.11	1.09	1.37	
14 vs 10	4.20	3.36	0.84	1.34	
14 vs 11	4.20	3.48	0.72	1.31	
14 vs 12	4.20	3.57	0.63	1.27	
14 vs 13	4.20	4.19	0.01	1.20	
13 vs 1	4.19	1.36	2.83	1.45	*
13 vs 2	4.19	1.42	2.77	1.45	*
13 vs 3	4.19	1.64	2.55	1.44	*
13 vs 4	4.19	2.10	2.09	1.42	*
13 vs 6	4.19	2.87	1.32	1.40	
13 vs 7	4.19	2.96	1.23	1.39	
13 vs 8	4.19	3.07	1.12	1.37	
13 vs 9	4.19	3.11	1.08	1.34	
13 vs 10	4.19	3.36	0.83	1.31	
13 vs 11	4.19	3.48	0.71	1.27	
13 vs 12	4.19	3.57	0.62	1.20	
12 vs 1	3.57	1.36	2.21	1.45	*
12 vs 2	3.57	1.42	2.15	1.44	*
12 vs 3	3.57	1.64	1.93	1.43	*
12 vs 4	3.57	1.66	1.91	1.42	*
12 vs 5	3.57	2.10	1.47	1.40	*
12 vs 6	3.57	2.87	0.70	1.39	
12 vs 7	3.57	2.96	0.61	1.37	
12 vs 8	3.57	3.07	0.50	1.34	
12 vs 9	3.57	3.11	0.46	1.31	

TABLE E. 13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	3.57	3.36	0.21	1.27	
12 vs 11	3.57	3.48	0.09	1.20	
11 vs 1	3.48	1.36	2.12	1.44	*
11 vs 2	3.48	1.42	2.06	1.43	*
11 vs 3	3.48	1.64	1.84	1.42	*
11 vs 4	3.48	1.66	1.82	1.40	*
11 vs 5	3.48	2.10	1.38	1.39	
11 vs 6	3.48	2.87	0.61	1.37	
11 vs 7	3.48	2.96	0.52	1.34	
11 vs 8	3.48	3.07	0.41	1.31	
11 vs 9	3.48	3.11	0.37	1.27	
11 vs 10	3.48	3.36	0.12	1.20	
10 vs 1	3.36	1.36	2.00	1.43	*
10 vs 2	3.36	1.42	1.94	1.42	*
10 vs 3	3.36	1.64	1.72	1.40	*
10 vs 4	3.36	1.66	1.70	1.39	*
10 vs 5	3.36	2.10	1.26	1.37	
10 vs 6	3.36	2.87	0.49	1.34	
10 vs 7	3.36	2.96	0.40	1.31	
10 vs 8	3.36	3.07	0.29	1.27	
10 vs 9	3.36	3.11	0.25	1.20	
9 vs 1	3.11	1.36	1.75	1.42	*
9 vs 2	3.11	1.42	1.69	1.40	*
9 vs 3	3.11	1.64	1.47	1.39	*
9 vs 4	3.11	1.66	1.45	1.37	*
9 vs 5	3.11	2.10	1.01	1.34	
9 vs 6	3.11	2.87	0.24	1.31	
9 vs 7	3.11	2.96	0.15	1.27	
9 vs 8	3.11	3.07	0.04	1.20	
8 vs 1	3.07	1.36	1.71	1.40	*
8 vs 2	3.07	1.42	1.65	1.39	*
8 vs 3	3.07	1.64	1.43	1.37	*
8 vs 4	3.07	1.66	1.41	1.34	*
8 vs 5	3.07	2.10	0.97	1.31	
8 vs 6	3.07	2.87	0.20	1.27	
8 vs 7	3.07	2.96	0.11	1.20	
7 vs 1	2.96	1.36	1.60	1.39	*
7 vs 2	2.96	1.42	1.54	1.37	*
7 vs 3	2.96	1.64	1.32	1.34	
7 vs 4	2.96	1.66	1.30	1.31	
7 vs 5	2.96	2.10	0.86	1.27	
7 vs 6	2.96	2.87	0.09	1.20	
6 vs 1	2.87	1.36	1.51	1.37	*
6 vs 2	2.87	1.42	1.45	1.34	*

TABLE E. 13 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	2.87	1.64	1.23	1.31	
6 vs 4	2.87	1.66	1.21	1.27	
6 vs 5	2.87	2.10	0.77	1.20	
5 vs 1	2.10	1.36	0.74	1.34	
5 vs 2	2.10	1.42	0.68	1.31	
5 vs 3	2.10	1.64	0.46	1.27	
5 vs 4	2.10	1.66	0.44	1.20	
4 vs 1	1.66	1.36	0.30	1.31	
4 vs 2	1.66	1.42	0.24	1.27	
4 vs 3	1.66	1.64	0.02	1.20	
3 vs 1	1.64	1.36	0.28	1.27	
3 vs 2	1.64	1.42	0.22	1.20	
2 vs 1	1.42	1.36	0.06	1.20	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.14 MEANS OF INTERACTION BETWEEN FACTORS B, C, AND D FOR RMS OF TARDINESS

FACTOR LEVEL			MEANS	FACTOR LEVEL			MEANS
b_j	c_k	d_l		b_j	c_k	d_l	
b_1	c_1	d_1	3.91	b_1	c_1	d_2	3.74
b_2	c_1	d_1	6.74	b_2	c_1	d_2	5.54
b_3	c_1	d_1	8.53	b_3	c_1	d_2	4.11
b_4	c_1	d_1	4.87	b_4	c_1	d_2	4.85
b_5	c_1	d_1	1.56	b_5	c_1	d_2	1.77
b_6	cl	d_1	4.14	b_6	c_1	d_2	3.60
b_1	c_2	d_1	2.72	b_1	c_2	d_2	2.81
b_2	c_2	d_1	5.08	b_2	c_2	d_2	3.40
b_3	c_2	d_1	3.65	b_3	c_2	d_2	4.14
b_4	c_2	d_1	5.48	b_4	c_2	d_2	4.20
b_5	c_2	d_1	1.46	b_5	c_2	d_2	1.47
b_6	c_2	d_1	2.92	b_6	c_2	d_2	3.68

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C, AND D (FOR MEANS OF RMS OF TARDINESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	8.53	1.46	7.07	1.52	*
24 vs 2	8.53	1.47	7.06	1.52	*
24 vs 3	8.53	1.56	6.97	1.51	*
24 vs 4	8.53	1.77	6.76	1.51	*
24 vs 5	8.53	2.72	5.81	1.51	*
24 vs 6	8.53	2.81	5.72	1.50	*
24 vs 7	8.53	2.92	5.61	1.49	*
24 vs 8	8.53	3.40	5.13	1.49	*
24 vs 9	8.53	3.60	4.93	1.48	*
24 vs 10	8.53	3.65	4.88	1.47	*
24 vs 11	8.53	3.68	4.85	1.46	*
24 vs 12	8.53	3.74	4.79	1.45	*
24 vs 13	8.53	3.91	4.62	1.45	*
24 vs 14	8.53	4.11	4.42	1.44	*
24 vs 15	8.53	4.14	4.39	1.43	*
24 vs 16	8.53	4.14	4.39	1.42	*
24 vs 17	8.53	4.20	4.33	1.40	*
24 vs 18	8.53	4.85	3.68	1.39	*
24 vs 19	8.53	4.87	3.66	1.37	*
24 vs 20	8.53	5.08	3.45	1.34	*
24 vs 21	8.53	5.48	3.05	1.31	*
24 vs 22	8.53	5.54	2.99	1.27	*
24 vs 23	8.53	6.74	1.79	1.20	*
23 vs 1	6.74	1.46	5.28	1.52	*
23 vs 2	6.74	1.47	5.27	1.51	*
23 vs 3	6.74	1.56	5.18	1.51	*
23 vs 4	6.74	1.77	4.97	1.51	*
23 vs 5	6.74	2.72	4.02	1.50	*
23 vs 6	6.74	2.81	3.93	1.49	*
23 vs 7	6.74	2.92	3.82	1.49	*
23 vs 8	6.74	3.40	3.34	1.48	*
23 vs 9	6.74	3.60	3.14	1.47	*
23 vs 10	6.74	3.65	3.09	.1.46	*
23 vs 11	6.74	3.68	3.06	1.45	*
23 vs 12	6.74	3.74	3.00	1.45	*
23 vs 13	6.74	3.91	2.83	1.44	*
23 vs 14	6.74	4.11	2.63	1.43	*
23 vs 15	6.74	4.14	2.60	1.42	*
23 vs 16	6.74	4.14	2.60	1.40	*
23 vs 17	6.74	4.20	2.54	1.39	*
23 vs 18	6.74	4.85	1.89	1.37	*
23 vs 19	6.74	4.87	1.87	1.34	*
23 vs 20	6.74	5.08	1.66	1.31	*

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 21	6.74	5.48	1.26	1.27	
23 vs 22	6.74	5.54	1.20	1.20	
22 vs 1	5.54	1.46	4.08	1.51	*
22 vs 2	5.54	1.47	4.07	1.51	*
22 vs 3	5.54	1.56	3.98	1.51	*
22 vs 4	5.54	1.77	3.77	1.50	*
22 vs 5	5.54	2.72	2.82	1.49	*
22 vs 6	5.54	2.81	2.73	1.49	*
22 vs 7	5.54	2.92	2.62	1.48	*
22 vs 8	5.54	3.40	2.14	1.47	*
22 vs 9	5.54	3.60	1.94	1.46	*
22 vs 10	5.54	3.65	1.89	1.45	*
22 vs 11	5.54	3.68	1.86	1.45	*
22 vs 12	5.54	3.74	1.80	1.44	*
22 vs 13	5.54	3.91	1.63	1.43	*
22 vs 14	5.54	4.11	1.43	1.42	*
22 vs 15	5.54	4.14	1.40	1.40	*
22 vs 16	5.54	4.14	1.40	1.39	*
22 vs 17	5.54	4.20	1.34	1.37	
22 vs 18	5.54	4.85	0.69	1.34	
22 vs 19	5.54	4.87	0.67	1.31	
22 vs 20	5.54	5.08	0.46	1.27	
22 vs 21	5.54	5.48	0.06	1.20	
21 vs 1	5.48	1.46	4.02	1.51	*
21 vs 2	5.48	1.47	4.01	1.51	*
21 vs 3	5.48	1.56	3.92	1.50	*
21 vs 4	5.48	1.77	3.71	1.49	*
21 vs 5	5.48	2.72	2.76	1.49	*
21 vs 6	5.48	2.81	2.67	1.48	*
21 vs 7	5.48	2.92	2.56	1.47	*
21 vs 8	5.48	3.40	2.08	1.46	*
21 vs 9	5.48	3.60	1.88	1.45	*
21 vs 10	5.48	3.65	1.83	1.45	*
21 vs 11	5.48	3.68	1.80	1.44	*
21 vs 12	5.48	3.74	1.74	1.43	*
21 vs 13	5.48	3.91	1.57	1.42	*
21 vs 14	5.48	4.11	1.37	1.40	
21 vs 15	5.48	4.14	1.34	1.39	
21 vs 16	5.48	4.14	1.34	1.37	
21 vs 17	5.48	4.20	1.28	1.34	
21 vs 18	5.48	4.85	0.63	1.31	
21 vs 19	5.48	4.87	0.61	1.27	
21 vs 20	5.48	5.08	0.40	1.20	
20 vs 1	5.08	1.46	3.62	1.51	*

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
20 vs 2	5.08	1.47	3.61	1.50	*
20 vs 3	5.08	1.56	3.52	1.49	*
20 vs 4	5.08	1.77	3.31	1.49	*
20 vs 5	5.08	2.72	2.36	1.48	*
20 vs 6	5.08	2.81	2.27	1.47	*
20 vs 7	5.08	2.92	2.16	1.46	*
20 vs 8	5.08	3.40	1.68	1.45	*
20 vs 9	5.08	3.60	1.48	1.45	*
20 vs 10	5.08	3.65	1.43	1.44	
20 vs 11	5.08	3.68	1.40	1.43	
20 vs 12	5.08	3.74	1.34	1.42	
20 vs 13	5.08	3.91	1.17	1.40	
20 vs 14	5.08	4.11	0.97	1.39	
20 vs 15	5.08	4.14	0.94	1.37	
20 vs 16	5.08	4.14	0.94	1.34	
20 vs 17	5.08	4.20	0.88	1.31	
20 vs 18	5.08	4.85	0.23	1.27	
20 vs 19	5.08	4.87	0.21	1.20	
19 vs 1	4.87	1.46	3.41	1.50	*
19 vs 2	4.87	1.47	3.40	1.49	*
19 vs 3	4.87	1.56	3.31	1.49	*
19 vs 4	4.87	1.77	3.10	1.48	*
19 vs 5	4.87	2.72	2.15	1.47	*
19 vs 6	4.87	2.81	2.06	1.46	*
19 vs 7	4.87	2.92	1.95	1.45	*
19 vs 8	4.87	3.40	1.47	1.45	*
19 vs 9	4.87	3.60	1.27	1.44	
19 vs 10	4.87	3.65	1.22	1.43	
19 vs 11	4.87	3.68	1.19	1.42	
19 vs 12	4.87	3.74	1.13	1.40	
19 vs 13	4.87	3.91	0.96	1.39	
19 vs 14	4.87	4.11	0.76	1.37	
19 vs 15	4.87	4.14	0.73	1.34	
19 vs 16	4.87	4.14	0.73	1.31	
19 vs 17	4.87	4.20	0.67	1.27	
19 vs 16	4.87	4.85	0.02	1.20	
18 vs 1	4.85	1.46	3.39	1.49	*
18 vs 2	4.85	1.47	3.38	1.49	*
18 vs 3	4.85	1.56	3.29	1.48	*
18 vs 4	4.85	1.77	3.08	1.47	*
18 vs 5	4.85	2.72	2.13	1.46	*
18 vs 6	4.85	2.81	2.04	1.45	*
18 vs 7	4.85	2.92	1.93	1.45	*
18 vs 8	4.85	3.40	1.45	1.44	*

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	4.85	3.60	1.25	1.43	
18 vs 10	4.85	3.65	1.20	1.42	
18 vs 11	4.85	3.68	1.17	1.40	
18 vs 12	4.85	3.74	1.11	1.39	
18 vs 13	4.85	3.91	0.94	1.37	
18 vs 14	4.85	4.11	0.74	1.34	
18 vs 15	4.85	4.14	0.71	1.31	
18 vs 16	4.85	4.14	0.71	1.27	
18 vs 17	4.85	4.20	0.65	1.20	
17 vs 1	4.20	1.46	2.74	1.49	*
17 vs 2	4.20	1.47	2.73	1.48	*
17 vs 3	4.20	1.56	2.64	1.47	*
17 vs 4	4.20	1.77	2.43	1.46	*
17 vs 5	4.20	2.72	1.48	1.45	*
17 vs 6	4.20	2.81	1.39	1.45	
17 vs 7	4.20	2.92	1.28	1.44	
17 vs 8	4.20	3.40	0.80	1.43	
17 vs 9	4.20	3.60	0.60	1.42	
17 vs 10	4.20	3.65	0.55	1.40	
17 vs 11	4.20	3.68	0.52	1.39	
17 vs 12	4.20	3.74	0.46	1.37	
17 vs 13	4.20	3.91	0.29	1.34	
17 vs 14	4.20	4.11	0.09	1.31	
17 vs 15	4.20	4.14	0.08	1.27	
17 vs 16	4.20	4.14	0.06	1.20	
16 vs 1	4.14	1.46	2.68	1.48	*
16 vs 2	4.14	1.47	2.67	1.47	*
16 vs 3	4.14	1.56	2.58	1.46	*
16 vs 4	4.14	1.77	2.37	1.45	*
16 vs 5	4.14	2.72	1.42	1.45	
16 vs 6	4.14	2.81	1.33	1.44	
16 vs 7	4.14	2.92	1.22	1.43	
16 vs 8	4.14	3.40	0.74	1.42	
16 vs 9	4.14	3.60	0.54	1.40	
16 vs 10	4.14	3.65	0.49	1.39	
16 vs 11	4.14	3.68	0.46	1.37	
16 vs 12	4.14	3.74	0.40	1.34	
16 vs 13	4.14	3.91	0.23	1.31	
16 vs 14	4.14	4.11	0.03	1.27	
16 vs 15	4.14	4.14	0.00	1.20	
15 vs 1	4.14	1.46	2.68	1.47	*
15 vs 2	4.14	1.47	2.67	1.46	*
15 vs 3	4.14	1.56	2.58	1.45	*
15 vs 4	4.14	1.77	2.37	1.45	*

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	4.14	2.72	1.42	1.44	
15 vs 6	4.14	2.81	1.33	1.43	
15 vs 7	4.14	2.92	1.22	1.42	
15 vs 8	4.14	3.40	0.74	1.40	
15 vs 9	4.14	3.60	0.54	1.39	
15 vs 10	4.14	3.65	0.49	1.37	
15 vs 11	4.14	3.68	0.46	1.34	
15 vs 12	4.14	3.74	0.40	1.31	
15 vs 13	4.14	3.91	0.23	1.27	
15 vs 14	4.14	4.11	0.03	1.20	
15 vs 1	4.11	2.46	2.65	1.46	*
14 vs 2	4.11	1.47	2.64	1.45	*
14 vs 3	4.11	1.56	2.55	1.45	*
14 vs 4	4.11	1.77	2.34	1.44	*
14 vs 5	4.11	2.72	1.39	1.43	
14 vs 6	4.11	2.81	1.30	1.42	
14 vs 7	4.11	2.92	1.19	1.40	
14 vs 8	4.11	3.40	0.71	1.39	
14 vs 9	4.11	3.60	0.51	1.37	
14 vs 10	4.11	3.65	0.46	1.34	
14 vs 11	4.11	3.68	0.43	1.31	
14 vs 12	4.11	3.74	0.37	1.27	
14 vs 13	4.11	3.91	0.20	1.20	
13 vs 1	3.91	1.46	2.45	1.45	*
13 vs 2	3.91	1.47	2.44	1.45	*
13 vs 3	3.91	1.56	2.35	1.44	*
13 vs 4	3.91	1.77	2.14	1.43	*
13 vs 5	3.91	2.72	1.19	1.42	
13 vs 6	3.91	2.81	1.10	1.40	
13 vs 7	3.91	2.92	0.99	1.39	
13 vs 8	3.91	3.40	0.51	1.37	
13 vs 9	3.91	3.60	0.31	1.34	
13 vs 10	3.91	3.65	0.26	1.31	
13 vs 11	3.91	3.68	0.23	1.27	
13 vs 12	3.91	3.74	0.17	1.20	
12 vs 1	3.74	1.46	2.28	1.45	*
12 vs 2	3.74	1.47	2.27	1.44	*
12 vs 3	3.74	1.56	2.18	1.43	*
12 vs 4	3.74	1.77	1.97	1.42	*
12 vs 5	3.74	2.72	1.02	1.40	
12 vs 6	3.74	2.81	0.93	1.39	
12 vs 7	3.74	2.92	0.82	1.37	
12 vs 8	3.74	3.40	0.34	1.34	
12 vs 9	3.74	3.60	0.14	1.31	

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	3.74	3.65	0.09	1.27	
12 vs 11	3.74	3.68	0.06	1.20	
11 vs 1	3.68	1.46	2.22	1.44	*
11 vs 2	3.68	1.47	2.21	1.43	*
11 vs 3	3.68	1.56	2.12	1.42	*
11 vs 4	3.68	1.77	1.91	1.40	*
11 vs 5	3.68	2.72	0.96	1.39	
11 vs 6	3.68	2.81	0.87	1.37	
11 vs 7	3.68	2.92	0.76	1.34	
11 vs 8	3.68	3.40	0.28	1.31	
11 vs 9	3.68	3.60	0.08	1.27	
11 vs 10	3.68	3.65	0.03	1.20	
10 vs 1	3.65	1.46	2.19	1.43	*
10 vs 2	3.65	1.47	2.18	1.42	*
10 vs 3	3.65	1.56	2.09	1.40	*
10 vs 4	3.65	1.77	1.88	1.39	*
10 vs 5	3.65	2.72	0.93	1.37	
10 vs 6	3.65	2.81	0.84	1.34	
10 vs 7	3.65	2.92	0.73	1.31	
10 vs 8	3.65	3.40	0.25	1.27	
10 vs 9	3.65	3.60	0.05	1.20	
9 vs 1	3.60	1.46	2.14	1.42	*
9 vs 2	3.60	1.47	2.13	1.40	*
9 vs 3	3.60	1.56	2.04	1.39	*
9 vs 4	3.60	1.77	1.83	1.37	*
9 vs 5	3.60	2.72	0.88	1.34	
9 vs 6	3.60	2.81	0.79	1.31	
9 vs 7	3.60	2.92	0.68	1.27	
9 vs 8	3.60	3.40	0.20	1.20	
8 vs 1	3.40	1.46	1.94	1.40	*
8 vs 2	3.40	1.47	1.93	1.39	*
8 vs 3	3.40	1.56	1.84	1.37	*
8 vs 4	3.40	1.77	1.63	1.34	*
8 vs 5	3.40	2.72	0.68	1.31	
8 vs 6	3.40	2.81	0.59	1.27	
8 vs 7	3.40	2.92	0.48	1.20	
7 vs 1	2.92	1.46	1.46	1.39	*
7 vs 2	2.92	1.47	1.45	1.37	*
7 vs 3	2.92	1.56	1.36	1.34	*
7 vs 4	2.92	1.77	1.15	1.31	
7 vs 5	2.92	2.72	0.20	1.27	
7 vs 6	2.92	2.81	0.11	1.20	
6 vs 1	2.81	1.46	1.35	1.37	
6 vs 2	2.81	1.47	1.34	1.34	

TABLE E.15 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	2.81	1.56	1.25	1.31	
6 vs 4	2.81	1.77	1.04	1.27	
6 vs 5	2.81	2.72	0.09	1.20	
5 vs 1	2.72	1.46	1.26	1.34	
5 vs 2	2.72	1.47	1.25	1.31	
5 vs 3	2.72	1.56	1.16	1.27	
5 vs 4	2.72	1.77	0.95	1.20	
4 vs 1	1.77	1.46	0.31	1.31	
4 vs 2	1.77	1.47	0.30	1.27	
4 vs 3	1.77	1.56	0.21	1.20	
3 vs 1	1.56	1.46	0.10	1.27	
3 vs 2	1.56	1.47	0.09	1.20	
2 vs 1	1.47	1.46	0.01	1.20	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.16 MEANS OF INTERACTION BETWEEN FACTORS A AND B FOR MEAN WIP

FACTOR LEVEL a_i	b_j	MEANS	FACTOR LEVEL a_i	b_j	MEANS
a_1	b_1	2.44	a_2	b_1	2.42
a_1	b_2	2.69	a_2	b_2	2.46
a_1	b_3	3.29	a_2	b_3	2.36
a_1	b_4	2.92	a_2	b_4	2.44
a_1	b_5	2.94	a_2	b_5	2.47
a_1	b_6	2.82	a_2	b_6	2.55

TABLE E.17 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	3.29	2.36	0.93	0.47	*
12 vs 2	3.29	2.42	0.87	0.46	*
12 vs 3	3.29	2.44	0.85	0.46	*
12 vs 4	3.29	2.44	0.85	0.46	*
12 vs 5	3.29	2.46	0.83	0.45	*
12 vs 6	3.29	2.47	0.82	0.45	*
12 vs 7	3.29	2.55	0.74	0.44	*
12 vs 8	3.29	2.69	0.60	0.43	*
12 vs 9	3.29	2.82	0.47	0.42	*
12 vs 10	3.29	2.92	0.37	0.41	
12 vs 11	3.29	2.94	0.35	0.39	
11 vs 1	2.94	2.36	0.58	0.46	*
11 vs 2	2.94	2.42	0.52	0.46	*
11 vs 3	2.94	2.44	0.50	0.46	*
11 vs 4	2.94	2.44	0.50	0.45	*
11 vs 5	2.94	2.46	0.48	0.45	*
11 vs 6	2.94	2.47	0.47	0.44	*
11 vs 7	2.94	2.55	0.39	0.43	
11 vs 8	2.94	2.69	0.25	0.42	
11 vs 9	2.94	2.82	0.12	0.41	
11 vs 10	2.94	2.92	0.02	0.39	
10 vs 1	2.92	2.36	0.56	0.46	*
10 vs 2	2.92	2.42	0.50	0.46	*
10 vs 3	2.92	2.44	0.48	0.45	*
10 vs 4	2.92	2.44	0.48	0.45	*
10 vs 5	2.92	2.46	0.46	0.44	*
10 vs 6	2.92	2.47	0.45	0.43	*
10 vs 7	2.92	2.55	0.37	0.42	
10 vs 8	2.92	2.69	0.23	0.41	
10 vs 9	2.92	2.82	0.10	0.39	
9 vs 1	2.82	2.36	0.46	0.46	*
9 vs 2	2.82	2.42	0.40	0.45	
9 vs 3	2.82	2.44	0.38	0.45	
9 vs 4	2.82	2.44	0.38	0.44	
9 vs 5	2.82	2.46	0.36	0.43	
9 vs 6	2.82	2.47	0.35	0.42	
9 vs 7	2.82	2.55	0.27	0.41	
9 vs 8	2.82	2.69	0.13	0.39	
8 vs 1	2.69	2.36	0.33	0.45	
8 vs 2	2.69	2.42	0.27	0.45	
8 vs 3	2.69	2.44	0.25	0.44	
8 vs 4	2.69	2.44	0.25	0.43	
8 vs 5	2.69	2.46	0.23	0.42	

TABLE E.17 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	2.69	2.47	0.22	0.41	
8 vs 7	2.69	2.55	0.14	0.39	
7 vs 1	2.55	2.36	0.19	0.45	
7 vs 2	2.55	2.42	0.13	0.44	
7 vs 3	2.55	2.44	0.11	0.43	
7 vs 4	2.55	2.44	0.11	0.42	
7 vs 5	2.55	2.46	0.09	0.41	
7 vs 6	2.55	2.47	0.08	0.39	
6 vs 1	2.47	2.36	0.11	0.44	
6 vs 2	2.47	2.42	0.05	0.43	
6 vs 3	2.47	2.44	0.03	0.42	
6 vs 4	2.47	2.44	0.03	0.41	
6 vs 5	2.47	2.46	0.01	0.39	
5 vs 1	2.46	2.36	0.10	0.43	
5 vs 2	2.46	2.42	0.04	0.42	
5 vs 3	2.46	2.44	0.02	0.41	
5 vs 4	2.46	2.44	0.02	0.39	
4 vs 1	2.44	2.36	0.08	0.42	
4 vs 2	2.44	2.42	0.02	0.41	
4 vs 3	2.44	2.44	0.00	0.39	
3 vs 1	2.44	2.36	0.08	0.41	
3 vs 2	2.44	2.42	0.02	0.39	
2 vs 1	2.42	2.36	0.06	0.39	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.18 MEANS OF INTERACTION BETWEEN FACTORS A AND C FOR MEAN WIP

FACTOR LEVEL a_i	c_k	MEANS	FACTOR LEVEL a_i	c_k	MEANS
a_1	c_1	4.41	a_2	c_1	2.81
a_1	c_2	2.13	a_2	c_2	2.10

TABLE E.19 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND C (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	4.41	2.10	2.31	0.24	*
4 vs 2	4.41	2.13	2.28	0.24	*
4 vs 3	4.41	2.81	1.60	0.22	*
3 vs 1	2.81	2.10	0.71	0.24	*
3 vs 2	2.81	2.13	0.68	0.22	*
2 vs 1	2.13	2.10	0.03	0.22	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.20 MEANS OF INTERACTION BETWEEN FACTORS A AND D FOR MEAN WIP

FACTOR LEVEL a_i d_1	MEANS	FACTOR LEVEL a_i d_1	MEANS
a_1 d_1	3.42	a_2 d_1	2.43
a_1 d_2	2.86	a_2 d_2	2.47

TABLE E.21 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND D (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs v	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	3.42	2.43	0.99	0.24	*
4 vs 2	3.42	2.47	0.95	0.24	*
4 vs 3	3.42	2.86	0.56	0.22	*
3 vs 1	2.86	2.43	0.43	0.24	*
3 vs 2	2.86	2.47	0.39	0.22	*
2 vs 1	2.47	2.43	0.04	0.22	

* = Significant at the 0.05 level
LSR = Least significant factor.

TABLE E.22 MEANS OF INTERACTION BETWEEN FACTORS B AND C FOR MEAN WIP

FACTOR LEVEL b_j	c_k	MEANS	FACTOR LEVEL b_j	c_k	MEANS
b_1	c_1	3.46	b_1	c_2	2.15
b_2	c_1	4.01	b_2	c_2	2.14
b_3	c_1	4.09	b_3	c_2	1.56
b_4	c_1	3.17	b_4	c_2	2.19
b_5	c_1	3.05	b_5	c_2	2.37
b_6	c_1	3.12	b_6	c_2	2.25

TABLE E.23 COMPARISON ON MEANS OF INTERACTION BETWEEN FACTORS B AND C (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	4.09	1.56	2.53	0.47	*
12 vs 2	4.09	2.14	1.95	0.46	*
12 vs 3	4.09	2.15	1.94	0.46	*
12 vs 4	4.09	2.19	1.90	0.46	*
12 vs 5	4.09	2.25	1.84	0.45	*
12 vs 6	4.09	2.37	1.72	0.45	*
12 vs 7	4.09	2.05	1.04	0.44	*
12 vs 8	4.09	3.12	0.97	0.43	*
12 vs 9	4.09	3.17	0.92	0.42	*
12 vs 10	4.09	3.46	0.63	0.41	*
12 vs 11	4.09	4.01	0.08	0.39	
11 vs 1	4.01	1.56	2.45	0.46	*
11 vs 2	4.01	2.14	1.87	0.46	*
11 vs 3	4.01	2.15	1.86	0.46	*
11 vs 4	4.01	2.19	1.82	0.45	*
11 vs 5	4.01	2.25	1.76	0.45	*
11 vs 6	4.01	2.37	1.64	0.44	*
11 vs 7	4.01	3.05	0.96	0.43	*
11 vs 8	4.01	3.12	0.89	0.42	*
11 vs 9	4.01	3.17	0.84	0.41	*
11 vs 10	4.01	3.46	0.55	0.39	*
10 vs 1	3.46	1.56	1.90	0.46	*
10 vs 2	3.46	2.14	1.32	0.46	*
10 vs 3	3.46	2.15	1.31	0.45	*
10 vs 4	3.46	2.19	1.27	0.45	*
10 vs 5	3.46	2.25	1.21	0.44	*
10 vs 6	3.46	2.37	1.09	0.43	*
10 vs 7	3.46	3.05	0.41	0.42	
10 vs 8	3.46	3.12	0.34	0.41	
10 vs 9	3.46	3.17	0.29	0.39	
9 vs 1	3.17	1.56	1.61	0.46	*
9 vs 2	3.17	2.14	1.03	0.45	*
9 vs 3	3.17	2.15	1.02	0.45	*
9 vs 4	3.17	2.19	0.98	0.44	8
9 vs 5	3.17	2.25	0.92	0.43	*
9 vs 6	3.17	2.37	0.80	0.42	*
9 vs 7	3.17	3.05	0.12	0.41	
9 vs 8	3.17	3.12	0.05	0.39	
8 vs 1	3.12	1.56	1.56	0.45	*
8 vs 2	3.12	2.14	0.98	0.45	*
8 vs 3	3.12	2.15	0.97	0.44	*
8 vs 4	3.12	2.19	0.93	0.43	*
8 vs 5	3.12	2.25	0.87	0.42	*

TABLE E.23 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	3.12	2.37	0.75	0.41	*
8 vs 7	3.12	3.05	0.07	0.39	
7 vs 1	3.05	1.56	1.49	0.45	*
7 vs 2	3.05	2.14	0.91	0.44	*
7 vs 3	3.05	2.15	0.90	0.43	*
7 vs 4	3.05	2.19	0.86	0.42	*
7 vs 5	3.05	2.25	0.80	0.41	*
7 vs 6	3.05	2.37	0.68	0.39	*
6 vs 1	2.37	1.56	0.81	0.44	*
6 vs 2	2.37	2.14	0.23	0.43	
6 vs 3	2.37	2.15	0.22	0.42	
6 vs 4	2.37	2.19	0.18	0.41	
6 vs 5	2.37	2.25	0.12	0.39	
5 vs 1	2.25	1.56	0.69	0.43	*
5 vs 2	2.25	2.14	0.11	0.42	
5 vs 3	2.25	2.15	0.10	0.41	
5 vs 4	2.25	2.19	0.06	0.39	
4 vs 1	2.19	1.56	0.63	0.42	*
4 vs 2	2.19	2.14	0.05	0.41	
4 vs 3	2.19	2.15	0.04	0.39	
3 vs 1	2.15	1.56	0.59	0.41	*
3 vs 2	2.15	2.14	0.01	0.39	
2 vs 1	2.14	1.56	0.58	0.39	*

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.24 MEANS OF INTERACTION BETWEEN FACTORS B AND D FOR MEAN WIP

FACTOR LEVEL		MEANS	FACTOR LEVEL		MEANS
b_j	d_1		b_j	d_1	
b_1	d_1	2.90	b_1	d_2	2.71
b_2	d_1	3.49	b_2	d_2	2.66
b_3	d_1	3.08	b_3	d_2	2.57
b_4	d_1	2.53	b_4	d_2	2.83
b_5	d_1	2.70	b_5	d_2	2.70
b_6	d_1	2.84	b_6	d_2	2.52

TABLE E.25 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND D (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	3.49	2.52	0.97	0.47	*
12 vs 2	3.49	2.53	0.96	0.46	*
12 vs 3	3.49	2.57	0.92	0.46	*
12 vs 4	3.49	2.66	0.83	0.46	*
12 vs 5	3.49	2.70	0.79	0.45	*
12 vs 6	3.49	2.70	0.79	0.45	*
12 vs 7	3.49	2.71	0.78	0.44	*
12 vs 8	3.49	2.83	0.66	0.43	*
12 vs 9	3.49	2.84	0.65	0.42	*
12 vs 10	3.49	2.90	0.59	0.41	*
12 vs 11	3.49	3.08	0.41	0.39	*
11 vs 1	3.08	2.52	0.56	0.46	*
11 vs 2	3.08	2.53	0.55	0.46	*
11 vs 3	3.08	2.57	0.51	0.46	*
11 vs 4	3.08	2.66	0.42	0.45	
11 vs 5	3.08	2.70	0.38	0.45	
11 vs 6	3.08	2.70	0.38	0.44	
11 vs 7	3.08	2.71	0.37	0.43	
11 vs 8	3.08	2.83	0.25	0.42	
11 vs 9	3.08	2.84	0.24	0.41	
11 vs 10	3.08	2.90	0.18	0.39	
10 vs 1	2.90	2.52	0.38	0.46	
10 vs 2	2.90	2.53	0.37	0.46	
10 vs 3	2.90	2.57	0.33	0.45	
10 vs 4	2.90	2.66	0.24	0.45	
10 vs 5	2.90	2.70	0.20	0.44	
10 vs 6	2.90	2.70	0.20	0.43	
10 vs 7	2.90	2.71	0.19	0.42	
10 vs 8	2.90	2.83	0.07	0.41	
10 vs 9	2.90	2.84	0.06	0.39	
9 vs 1	2.84	2.52	0.32	0.46	
9 vs 2	2.84	2.53	0.31	0.45	
9 vs 3	2.84	2.57	0.27	0.45	
9 vs 4	2.84	2.66	0.18	0.44	
9 vs 5	2.84	2.70	0.14	0.43	
9 vs 6	2.84	2.70	0.14	0.42	
9 vs 7	2.84	2.71	0.13	0.41	
9 vs 8	2.84	2.83	0.01	0.39	
8 vs 1	2.83	2.52	0.31	0.45	
8 vs 2	2.83	2.53	0.30	0.45	
8 vs 3	2.83	2.57	0.26	0.44	
8 vs 4	2.83	2.66	0.17	0.43	
8 vs 5	2.83	2.70	0.13	0.42	

TABLE E.25 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	2.83	2.70	0.13	0.41	
8 vs 7	2.83	2.71	0.12	0.39	
7 vs 1	2.71	2.52	0.19	0.45	
7 vs 2	2.71	2.53	0.18	0.44	
7 vs 3	2.71	2.57	0.14	0.43	
7 vs 4	2.71	2.66	0.05	0.42	
7 vs 5	2.71	2.70	0.01	0.41	
7 vs 6	2.71	2.70	0.01	0.39	
6 vs 1	2.70	2.52	0.18	0.44	
6 vs 2	2.70	2.53	0.17	0.43	
6 vs 3	2.70	2.57	0.13	0.42	
6 vs 4	2.70	2.66	0.04	0.41	
6 vs 5	2.70	2.70	0.00	0.39	
5 vs 1	2.70	2.52	0.18	0.43	
5 vs 2	2.70	2.53	0.17	0.42	
5 vs 3	2.70	2.57	0.13	0.41	
5 vs 4	2.70	2.66	0.04	0.39	
4 vs 1	2.66	2.52	0.14	0.42	
4 vs 2	2.66	2.53	0.13	0.41	
4 vs 3	2.66	2.47	0.09	0.39	
3 vs 1	2.57	2.52	0.05	0.41	
3 vs 2	2.57	2.53	0.04	0.39	
2 vs 1	2.53	2.52	0.01	0.39	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.26 MEANS OF INTERACTION BETWEEN FACTORS A, B, AND C FOR MEAN WIP

FACTOR LEVEL a_i	b_j	c_k	MEANS	FACTOR LEVEL a_i	b_j	c_k	MEANS
a_1	b_1	c_1	4.34	a_2	b_1	c_1	2.58
a_1	b_2	c_1	5.16	a_2	b_2	c_1	2.87
a_1	b_3	c_1	4.96	a_2	b_3	c_1	3.22
a_1	b_4	c_1	3.60	a_2	b_4	c_1	2.74
a_1	b_5	c_1	3.55	a_2	b_5	c_1	2.55
a_1	b_6	c_1	3.34	a_2	b_6	c_1	2.84
a_1	b_1	c_2	2.05	a_2	b_1	c_2	2.26
al	b_2	c_2	2.22	a_2	b_2	c_2	2.06
a_1	b_3	c_2	1.62	a_2	b_3	c_2	1.50
a_1	b_4	c_2	2.24	a_2	b_4	c_2	2.15
a_1	b_5	c_2	2.34	a_2	b_5	c_2	2.39
a_1	b_6	c_2	2.30	a_2	b_6	c_2	2.20

TABLE E.27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (FOR MEANS OF WORK IN PROGRESS)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	5.16	1.50	3.66	0.69	*
24 vs 2	5.16	1.62	3.54	0.69	*
24 vs 3	5.16	2.05	3.11	0.69	*
24 vs 4	5.16	2.06	3.10	0.69	*
24 vs 5	5.16	2.15	3.01	0.69	*
24 vs 6	5.16	2.20	2.96	0.68	*
24 vs 7	5.16	2.22	2.94	0.68	*
24 vs 8	5.16	2.24	2.92	0.68	*
24 vs 9	5.16	2.26	2.90	0.67	*
24 vs 10	5.16	2.30	2.86	0.67	*
24 vs 11	5.16	2.34	2.82	0.66	*
24 vs 12	5.16	2.39	2.77	0.66	*
24 vs 13	5.16	2.55	2.61	0.66	*
24 vs 14	5.16	2.58	2.58	0.65	*
24 vs 15	5.16	2.74	2.42	0.65	*
24 vs 16	5.16	2.87	2.29	0.64	*
24 vs 17	5.16	2.89	2.27	0.64	*
24 vs 18	5.16	3.22	1.94	0.63	*
24 vs 19	5.16	3.34	1.82	0.62	*
24 vs 20	5.16	3.55	1.61	0.61	*
24 vs 21	5.16	3.60	1.56	0.60	*
24 vs 22	5.16	4.34	0.82	0.58	*
24 vs 23	5.16	4.96	0.20	0.55	
23 vs 1	4.96	1.50	3.46	0.69	*
23 vs 2	4.96	1.62	3.34	0.69	*
23 vs 3	4.96	2.05	2.91	0.69	*
23 vs 4	4.96	2.06	2.90	0.69	*
23 vs 5	4.96	2.15	2.81	0.68	*
23 vs 6	4.96	2.20	2.76	0.68	*
23 vs 7	4.96	2.22	2.74	0.68	*
23 vs 8	4.96	2.24	2.72	0.67	*
23 vs 9	4.96	2.26	2.70	0.67	*
23 vs 10	4.96	2.30	2.66	0.66	*
23 vs 11	4.96	2.34	2.62	0.66	*
23 vs 12	4.96	2.39	2.57	0.66	*
23 vs 13	4.96	2.55	2.41	0.65	*
23 vs 14	4.96	2.58	2.38	0.65	*
23 vs 15	4.96	2.74	2.22	0.64	*
23 vs 16	4.96	2.87	2.09	0.64	*
23 vs 17	4.96	2.89	2.07	0.63	*
23 vs 18	4.96	3.22	1.74	0.62	*
23 vs 19	4.96	3.34	1.62	0.61	*
23 vs 20	4.96	3.55	1.41	0.60	*

TABLE E.27 COMPARISON ON MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 21	4.96	3.60	1.36	0.58	*
23 vs 22	4.96	4.34	0.62	0.55	*
22 vs 1	4.34	1.50	2.84	0.69	*
22 vs 2	4.34	1.62	2.72	0.69	*
22 vs 3	4.34	2.05	2.29	0.69	*
22 vs 4	4.34	2.06	2.28	0.68	*
22 vs 5	4.34	2.15	2.19	0.68	*
22 vs 6	4.34	2.20	2.14	0.68	*
22 vs 7	4.34	2.22	2.12	0.67	*
22 vs 8	4.34	2.24	2.10	0.67	*
22 vs 9	4.34	2.26	2.08	0.66	*
22 vs 10	4.34	2.30	2.04	0.66	*
22 vs 11	4.34	2.34	2.00	0.66	*
22 vs 12	4.34	2.39	1.95	0.65	*
22 vs 13	4.34	2.55	1.79	0.65	*
22 vs 14	4.34	2.58	1.76	0.64	*
22 vs 15	4.34	2.74	1.60	0.64	*
22 vs 16	4.34	2.87	1.47	0.63	*
22 vs 17	4.34	2.89	1.45	0.62	*
22 vs 18	4.34	3.22	1.12	0.61	*
22 vs 19	4.34	3.34	1.00	0.60	*
22 vs 20	4.34	3.55	0.79	0.58	*
22 vs 21	4.34	3.60	0.74	0.55	*
21 vs 1	3.60	1.50	2.10	0.69	*
21 vs 2	3.60	1.62	1.98	0.69	*
21 vs 3	3.60	2.05	1.55	0.68	*
21 vs 4	3.60	2.06	1.54	0.68	*
21 vs 5	3.60	2.15	1.45	0.68	*
21 vs 6	3.60	2.20	1.40	0.67	*
21 vs 7	3.60	2.22	1.38	0.67	*
21 vs 8	3.60	2.24	1.36	0.66	*
21 vs 9	3.60	2.26	1.34	0.66	*
21 vs 10	3.60	2.30	1.30	0.66	*
21 vs 11	3.60	2.34	1.26	0.65	*
21 vs 12	3.60	2.39	1.21	0.65	*
21 vs 13	3.60	2.55	1.05	0.64	*
21 vs 14	3.60	2.58	1.02	0.64	*
21 vs 15	3.60	2.74	0.86	0.63	*
21 vs 16	3.60	2.87	0.73	0.62	*
21 vs 17	3.60	2.89	0.71	0.61	*
21 vs 18	3.60	3.22	0.38	0.60	
21 vs 19	3.60	3.34	0.26	0.58	
21 vs 20	3.60	3.55	0.05	0.55	
20 vs 1	3.55	1.50	2.05	0.69	*

TABLE E.27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
20 vs 2	3.55	1.62	1.93	0.68	*
20 vs 3	3.55	2.05	1.50	0.68	*
20 vs 4	3.55	2.06	1.49	0.68	*
20 vs 5	3.55	2.15	1.40	0.67	*
20 vs 6	3.55	2.20	1.35	0.67	*
20 vs 7	3.55	2.22	1.33	0.66	*
20 vs 8	3.55	2.24	1.31	0.66	*
20 vs 9	3.55	2.26	1.29	0.66	*
20 vs 10	3.55	2.30	1.25	0.65	*
20 vs 11	3.55	2.34	1.21	0.65	*
20 vs 12	3.55	2.39	1.16	0.54	*
20 vs 13	3.55	2.55	1.00	0.64	*
20 vs 14	3.55	2.58	0.97	0.63	*
20 vs 15	3.55	2.74	0.81	0.62	*
20 vs 16	3.55	2.87	0.68	0.61	*
20 vs 17	3.55	2.89	0.66	0.60	*
20 vs 18	3.55	3.22	0.33	0.58	
20 vs 19	3.55	3.34	0.21	0.55	
19 vs 1	3.34	1.50	1.84	0.68	*
19 vs 2	3.34	1.62	1.72	0.68	*
19 vs 3	3.34	2.05	1.29	0.68	*
19 vs 4	3.34	2.06	1.28	0.67	*
19 vs 5	3.34	2.15	1.19	0.67	*
19 vs 6	3.34	2.20	1.14	0.66	*
19 vs 7	3.34	2.22	1.12	0.66	*
19 vs 8	3.34	2.24	1.10	0.66	*
19 vs 9	3.34	2.26	1.08	0.65	*
19 vs 10	3.34	2.30	1.04	0.65	*
19 vs 11	3.34	2.34	1.00	0.64	*
19 vs 12	3.34	2.39	0.95	0.64	*
19 vs 13	3.34	2.55	0.79	0.63	*
19 vs 14	3.34	2.58	0.76	0.62	*
19 vs 15	3.34	2.74	0.60	0.61	
19 vs 16	3.34	2.87	0.47	0.60	
19 vs 17	3.34	2.89	0.45	0.58	
19 vs 18	3.34	3.22	0.12	0.55	
18 vs 1	3.22	1.50	1.72	0.68	*
18 vs 2	3.22	1.62	1.60	0.68	*
18 vs 3	3.22	2.05	1.17	0.67	*
18 vs 4	3.22	2.06	1.16	0.67	*
18 vs 5	3.22	2.15	1.07	0.66	*
18 vs 6	3.22	2.20	1.02	0.66	*
18 vs 7	3.22	2.22	1.00	0.66	*
18 vs 8	3.22	2.24	0.98	0.65	*

TABLE E.27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	3.22	2.26	0.96	0.65	*
18 vs 10	3.22	2.30	0.92	0.64	*
18 vs 11	3.22	2.34	0.88	0.64	*
18 vs 12	3.22	2.39	0.83	0.63	*
18 vs 13	3.22	2.55	0.67	0.62	*
18 vs 14	3.22	2.58	0.64	0.61	*
18 vs 15	3.22	2.74	0.48	0.60	
18 vs 16	3.22	2.87	0.35	0.58	
18 vs 17	3.22	2.89	0.33	0.55	
17 vs 1	2.89	1.50	1.39	0.68	*
17 vs 2	2.89	1.62	1.27	0.67	*
17 vs 3	2.89	2.05	0.84	0.67	*
17 vs 4	2.89	2.06	0.83	0.66	*
17 vs 5	2.89	2.15	0.74	0.66	*
17 vs 6	2.89	2.20	0.69	0.66	*
17 vs 7	2.89	2.22	0.67	0.65	*
17 vs 8	2.89	2.24	0.65	0.65	*
17 vs 9	2.89	2.26	0.63	0.64	
17 vs 10	2.89	2.30	0.59	0.64	
17 vs 11	2.89	2.34	0.55	0.63	
17 vs 12	2.89	2.39	0.50	0.62	
17 vs 13	2.89	2.55	0.34	0.61	
17 vs 14	2.89	2.58	0.31	0.60	
17 vs 15	2.89	2.74	0.15	0.58	
17 vs 16	2.89	2.87	0.02	0.55	
16 vs 1	2.87	1.50	1.37	0.67	*
16 vs 2	2.87	1.62	1.25	0.67	*
16 vs 3	2.87	2.05	0.82	0.66	*
16 vs 4	2.87	2.06	0.81	0.66	*
16 vs 5	2.87	2.15	0.72	0.66	*
16 vs 6	2.87	2.20	0.67	0.65	*
16 vs 7	2.87	2.22	0.65	0.65	*
16 vs 8	2.87	2.24	0.63	0.64	
16 vs 9	2.87	2.26	0.61	0.64	
16 vs 10	2.87	2.30	0.57	0.63	
16 vs 11	2.87	2.34	0.53	0.62	
16 vs 12	2.87	2.39	0.48	0.61	
16 vs 13	2.87	2.55	0.32	0.60	
16 vs 14	2.87	2.58	0.29	0.58	
16 vs 15	2.87	2.74	0.13	0.55	
15 vs 1	2.74	1.50	1.24	0.67	*
15 vs 2	2.74	1.62	1.12	0.66	*
15 vs 3	2.74	2.05	0.69	0.66	*
15 vs 4	2.74	2.06	0.68	0.66	*

TABLE E. 27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	2.74	2.15	0.59	0.65	
15 vs 6	2.74	2.20	0.54	0.65	
15 vs 7	2.74	2.22	0.52	0.64	
15 vs 8	2.74	2.24	0.50	0.64	
15 vs 9	2.74	2.26	0.48	0.63	
15 vs 10	2.74	2.30	0.44	0.62	
15 vs 11	2.74	2.34	0.40	0.61	
15 vs 12	2.74	2.39	0.35	0.60	
15 vs 13	2.74	2.55	0.19	0.58	
15 vs 14	2.74	2.58	0.16	0.55	
14 vs 1	2.58	1.50	1.08	0.66	*
14 vs 2	2.58	1.62	0.96	0.66	*
14 vs 3	2.58	2.05	0.53	0.66	
14 vs 4	2.58	2.06	0.52	0.65	
14 vs 5	2.58	2.15	0.43	0.65	
14 vs 6	2.58	2.20	0.38	0.64	
14 vs 7	2.58	2.22	0.36	0.64	
14 vs 8	2.58	2.24	0.34	0.63	
14 vs 9	2.58	2.26	0.32	0.62	
14 vs 10	2.58	2.30	0.28	0.61	
14 vs 11	2.58	2.34	0.24	0.60	
14 vs 12	2.58	2.39	0.19	0.58	
14 vs 13	2.58	2.55	0.03	0.55	
13 vs 1	2.55	1.50	1.05	0.66	*
13 vs 2	2.55	1.62	0.93	0.66	*
13 vs 3	2.55	2.05	0.50	0.65	
13 vs 4	2.55	2.06	0.49	0.65	
13 vs 5	2.55	2.15	0.40	0.64	
13 vs 6	2.55	2.20	0.35	0.64	
13 vs 7	2.55	2.22	0.33	0.63	
13 vs 8	2.55	2.24	0.31	0.62	
13 vs 9	2.55	2.26	0.29	0.61	
13 vs 10	2.55	2.30	0.25	0.60	
13 vs 11	2.55	2.34	0.21	0.58	
13 vs 12	2.55	2.39	0.16	0.55	
12 vs 1	2.39	1.50	0.89	0.66	*
12 vs 2	2.39	1.62	0.77	0.65	*
12 vs 3	2.39	2.05	0.34	0.65	
12 vs 4	2.39	2.06	0.33	0.64	
12 vs 5	2.39	2.15	0.24	0.64	
12 vs 6	2.39	2.20	0.19	0.63	
12 vs 7	2.39	2.22	0.17	0.62	
12 vs 8	2.39	2.24	0.15	0.61	
12 vs 9	2.39	2.26	0.13	0.60	

TABLE E.27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	2.39	2.30	0.09	0.58	
12 vs 11	2.39	2.34	0.05	0.55	
11 vs 1	2.34	1.50	0.84	0.65	*
11 vs 2	2.34	1.62	0.72	0.65	*
11 vs 3	2.34	2.05	0.29	0.64	
11 vs 4	2.34	2.06	0.28	0.64	
11 vs 5	2.34	2.15	0.19	0.63	
11 vs 6	2.34	2.20	0.14	0.62	
11 vs 7	2.34	2.22	0.12	0.61	
11 vs 8	2.34	2.24	0.10	0.60	
11 vs 9	2.34	2.26	0.08	0.58	
11 vs 10	2.34	2.30	0.04	0.55	
10 vs 1	2.30	1.50	0.80	0.65	*
10 vs 2	2.30	1.62	0.68	0.64	*
10 vs 3	2.30	2.05	0.25	0.64	
10 vs 4	2.30	2.06	0.24	0.63	
10 vs 5	2.30	2.15	0.15	0.62	
10 vs 6	2.30	2.20	0.10	0.61	
10 vs 7	2.30	2.22	0.08	0.60	
10 vs 8	2.30	2.24	0.06	0.58	
10 vs 9	2.30	2.26	0.04	0.55	
9 vs 1	2.26	1.50	0.76	0.64	*
9 vs 2	2.26	1.62	0.64	0.64	*
9 vs 3	2.26	2.05	0.21	0.63	
9 vs 4	2.26	2.06	0.20	0.62	
9 vs 5	2.26	2.15	0.11	0.61	
9 vs 6	2.26	2.20	0.06	0.60	
9 vs 7	2.26	2.22	0.04	0.58	
9 vs 8	2.26	2.24	0.02	0.55	
8 vs 1	2.24	1.50	0.74	0.64	*
8 vs 2	2.24	1.62	0.62	0.63	
8 vs 3	2.24	2.05	0.19	0.62	
8 vs 4	2.24	2.06	0.18	0.61	
8 vs 5	2.24	2.15	0.09	0.60	
8 vs 6	2.24	2.20	0.04	0.58	
8 vs 7	2.24	2.22	0.02	0.55	
7 vs 1	2.22	1.50	0.72	0.63	*
7 vs 2	2.22	1.62	0.60	0.62	
7 vs 3	2.22	2.05	0.17	0.61	
7 vs 4	2.22	2.06	0.16	0.60	
7 vs 5	2.22	2.15	0.07	0.58	
7 vs 6	2.22	2.20	0.02	0.55	
6 vs 1	2.20	1.50	0.70	0.62	*
6 vs 2	2.20	1.62	0.58	0.61	

TABLE E.27 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y9m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	2.20	2.05	0.15	0.60	
6 vs 4	2.20	2.06	0.14	0.58	
6 vs 5	2.20	2.15	0.05	0.55	
5 vs 1	2.15	1.50	0.65	0.61	*
5 vs 2	2.15	1.62	0.53	0.60	
5 vs 3	2.15	2.05	0.10	0.58	
5 vs 4	2.15	2.06	0.09	0.55	
4 vs 1	2.06	1.50	0.56	0.60	
4 vs 2	2.06	1.62	0.44	0.58	
4 vs 3	2.06	2.05	0.01	0.55	
3 vs 1	2.05	1.50	0.55	0.58	
3 vs 2	2.05	1.62	0.43	0.55	
2 vs 1	1.62	1.50	0.12	0.55	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.28 MEANS OF INTERACTION BETWEEN FACTORS A AND B FOR MEAN MACHINE UTILISATION

FACTOR LEVEL a_i	b_j	MEANS	FACTOR LEVEL a_i	b_j	MEANS
a_1	b_1	75.58	a_2	b_1	77.76
a_1	b_2	76.23	a_2	b_2	77.73
a_1	b_3	75.54	a_2	b_3	77.39
a_1	b_4	76.54	a_2	b_4	77.66
a_1	b_5	77.03	a_2	b_5	79.77
a_1	b_6	77.26	a_2	b_6	76.34

TABLE E.29 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (FOR MEANS OF MACHINE UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	79.77	75.54	4.23	1.43	*
12 vs 2	79.77	75.58	4.19	1.43	*
12 vs 3	79.77	76.23	3.54	1.42	*
12 vs 4	79.77	76.34	3.43	1.40	*
12 vs 5	79.77	76.54	3.23	1.39	*
12 vs 6	79.77	77.03	2.74	1.37	*
12 vs 7	79.77	77.26	2.51	1.36	*
12 vs 8	79.77	77.39	2.38	1.33	*
12 vs 9	79.77	77.66	2.11	1.30	*
12 vs 10	79.77	77.73	2.04	1.26	*
12 vs 11	79.77	77.76	2.01	1.19	*
11 vs 1	77.76	75.54	2.22	1.43	*
11 vs 2	77.76	75.58	2.18	1.42	*
11 vs 3	77.76	76.23	1.53	1.40	*
11 vs 4	77.76	76.34	1.42	1.39	*
11 vs 5	77.76	76.54	1.22	1.37	
11 vs 6	77.76	77.03	0.73	1.36	
11 vs 7	77.76	77.26	0.50	1.33	
11 vs 8	77.76	77.39	0.37	1.30	
11 vs 9	77.76	77.66	0.10	1.26	
11 vs 10	77.76	77.73	0.03	1.19	
10 vs 1	77.73	75.54	2.19	1.42	*
10 vs 2	77.73	75.58	2.15	1.40	*
10 vs 3	77.73	76.23	1.50	1.38	*
10 vs 4	77.73	76.34	1.39	1.37	*
10 vs 5	77.73	76.54	1.19	1.36	
10 vs 6	77.73	77.03	0.70	1.33	
10 vs 7	77.73	77.26	0.47	1.30	
10 vs 8	77.73	77.39	0.34	1.26	
10 vs 9	77.73	77.66	0.07	1.19	
9 vs 1	77.66	75.54	2.12	1.40	*
9 vs 2	77.66	75.58	2.08	1.39	*
9 vs 3	77.66	76.23	1.43	1.37	*
9 vs 4	77.66	76.34	1.32	1.36	
9 vs 5	77.66	76.54	1.12	1.33	
9 vs 6	77.66	77.03	0.63	1.30	
9 vs 7	77.66	77.26	0.40	1.26	
9 vs 8	77.66	77.39	0.27	1.19	
8 vs 1	77.39	75.54	1.85	1.39	*
8 vs 2	77.39	75.58	1.81	1.37	*
8 vs 3	77.39	76.23	1.16	1.36	
8 vs 4	77.39	76.34	1.05	1.33	
8 vs 5	77.39	76.54	0.85	1.30	

TABLE E.29 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND B (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	77.39	77.03	0.36	1.26	
8 vs 7	77.39	77.26	0.13	1.19	
7 vs 1	77.26	75.54	1.72	1.37	*
7 vs 2	77.26	75.58	1.68	1.36	*
7 vs 3	77.26	76.23	1.03	1.33	
7 vs 4	77.26	76.34	0.92	1.30	
7 vs 5	77.26	76.54	0.72	1.26	
7 vs 6	77.26	77.03	0.23	1.19	
6 vs 1	77.03	75.54	1.49	1.36	*
6 vs 2	77.03	75.58	1.45	1.33	*
6 vs 3	77.03	76.23	0.80	1.30	
6 vs 4	77.03	76.34	0.69	1.26	
6 vs 5	77.03	76.54	0.49	1.19	
5 vs 1	76.54	75.54	1.00	1.33	
5 vs 2	76.54	75.58	0.96	1.30	
5 vs 3	76.54	76.23	0.31	1.26	
5 vs 4	76.54	76.34	0.20	1.19	
4 vs 1	76.34	75.54	0.80	1.30	
4 vs 2	76.34	75.58	0.76	1.26	
4 vs 3	76.34	76.23	0.11	1.19	
3 vs 1	76.23	75.54	0.69	1.26	
3 vs 2	76.23	75.58	0.65	1.19	
2 vs 1	75.58	75.54	0.04	1.19	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E. 30 MEANS OF INTERACTION BETWEEN FACTORS A AND C FOR MEAN MACHINE UTILISATION

FACTOR LEVEL a_i	c_k	MEANS	FACTOR LEVEL a_i	c_k	MEANS
a_1	c_1	74.03	a_2	c_1	76.58
a_1	c_2	78.77	a_2	c_2	78.97

TABLE E.31 COMPARISON OF MEANS OF UTILISATION BETWEEN FACTORS A AND C (FOR MEANS OF MACHINE UTILISATION)

COMPARISION m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	78.97	74.03	4.94	0.75	*
4 vs 2	78.97	76.58	2.39	0.75	*
4 vs 3	78.97	78.77	0.20	0.69	
3 vs 1	78.77	74.03	4.74	0.73	
3 vs 2	78.77	76.58	2.19	0.69	*
2 vs 1	76.58	74.03	2.55	0.69	*

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.32 MEANS OF INTERACTION BETWEEN FACTORS B AND C FOR MEAN MACHINE UTILISATION

FACTOR LEVEL b_j	c_k	MEANS	FACTOR LEVEL b_j	c_k	MEANS
b_1	c_1	74.17	b_1	c_2	79.17
b_2	c_1	75.31	b_2	c_2	78.85
b_3	c_1	74.44	b_3	c_2	78.49
b_4	c_1	75.48	b_4	c_2	78.73
b_5	c_1	77.72	b_5	c_2	79.08
b_6	c_1	74.73	b_6	c_2	78.89

TABLE E.33 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (FOR MEANS OF MACHINE UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	79.17	74.17	5.00	1.43	*
12 vs 2	79.17	74.44	4.73	1.43	*
12 vs 3	79.17	74.73	4.44	1.42	*
12 vs 4	79.17	75.31	3.86	1.40	*
12 vs 5	79.17	75.48	3.69	1.39	*
12 vs 6	79.17	77.72	1.45	1.37	*
12 vs 7	79.17	78.49	0.68	1.36	
12 vs 8	79.17	78.73	0.44	1.33	
12 vs 9	79.17	78.85	0.32	1.30	
12 vs 10	79.17	78.89	0.28	1.26	
12 vs 11	79.17	79.08	0.09	1.19	
11 vs 1	79.08	74.17	4.91	1.43	*
11 vs 2	79.08	74.44	4.64	1.42	*
11 vs 3	79.08	74.73	4.35	1.40	*
11 vs 4	79.08	75.31	3.77	1.39	*
11 vs 5	79.08	75.48	3.60	1.37	*
11 vs 6	79.08	77.72	1.36	1.36	*
11 vs 7	79.08	78.49	0.59	1.33	
11 vs 8	79.08	78.73	0.35	1.30	
11 vs 9	79.08	78.85	0.23	1.26	
11 vs 10	79.08	78.89	0.19	1.19	
10 vs 1	78.89	74.17	4.72	1.42	*
10 vs 2	78.89	74.44	4.45	1.40	*
10 vs 3	78.89	74.73	4.16	1.39	*
10 vs 4	78.89	75.31	3.58	1.37	*
10 vs 5	78.89	75.48	3.41	1.36	*
10 vs 6	78.89	77.72	1.17	1.33	
10 vs 7	78.89	78.49	0.40	1.30	
10 vs 8	78.89	78.73	0.16	1.26	
10 vs 9	78.89	78.85	0.04	1.19	
9 vs 1	78.85	74.17	4.68	1.40	*
9 vs 2	78.85	74.44	4.41	1.39	*
9 vs 3	78.85	74.73	4.12	1.37	*
9 vs 4	78.85	75.31	3.54	1.36	*
9 vs 5	78.85	75.48	3.37	1.33	*
9 vs 6	78.85	77.72	1.13	1.30	
9 vs 7	78.85	78.49	0.36	1.26	
9 vs 8	78.85	78.73	0.12	1.19	
8 vs 1	78.73	76.17	4.56	1.39	*
8 vs 2	78.73	74.44	4.29	1.37	*
8 vs 3	78.73	74.73	4.00	1.36	*
8 vs 4	78.73	75.31	3.42	1.33	*
8 vs 5	78.73	75.48	3.25	1.30	*

TABLE E.33 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	78.73	77.72	1.01	1.26	
8 vs 7	78.73	78.49	0.24	1.19	
7 vs 1	78.49	74.17	4.32	1.37	*
7 vs 2	78.49	74.44	4.05	1.36	*
7 vs 3	78.49	74.73	3.76	1.33	*
7 vs 4	78.49	75.31	3.18	1.30	*
7 vs 5	78.49	75.48	3.01	1.26	*
7 vs 6	78.49	77.72	0.77	1.19	
6 vs 1	77.72	74.17	3.55	1.36	*
6 vs 2	77.72	74.44	3.28	1.33	*
6 vs 3	77.72	74.73	2.99	1.30	*
6 vs 4	77.72	75.31	2.41	1.26	*
6 vs 5	77.72	75.48	2.24	1.19	*
5 vs 1	75.48	74.17	1.31	1.33	
5 vs 2	75.48	74.44	1.04	1.30	
5 vs 3	75.48	74.73	0.75	1.26	
5 vs 4	75.48	75.31	0.17	1.19	
4 vs 1	75.31	74.17	1.14	1.30	
4 vs 2	75.31	74.44	0.87	1.26	
4 vs 3	75.31	74.73	0.58	1.19	
3 vs 1	74.73	74.17	0.56	1.26	
3 vs 2	74.73	74.44	0.29	1.19	
2 vs 1	74.44	74.17	0.27	1.19	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.34 MEANS OF INTERACTION BETWEEN FACTORS C AND D FOR MEAN MACHINE UTILISATION

FACTOR LEVEL c_k	d_l	MEANS	FACTOR LEVEL c_k	d_l	MEANS
c_1	d_1	74.67	c_2	d_1	78.83
c_1	d_2	75.94	c_2	d_2	78.91

TABLE E.35 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS C AND D (FOR MEANS OF MACHINE UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	78.91	74.67	4.24	0.75	*
4 vs 2	78.91	75.94	2.97	0.73	*
4 vs 3	78.91	78.83	0.08	0.69	
3 vs 1	78.83	74.67	4.16	0.73	*
3 vs 2	78.83	75.94	2.89	0.69	*
2 vs 1	75.94	74.67	1.27	0.69	*

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.36 MEANS OF INTERACTION BETWEEN FACTORS A, B, AND C FOR MEAN MACHINE UTILISATION

FACTOR LEVEL a_i	b_j	c_k	MEANS	FACTOR LEVEL a_i	b_j	c_k	MEANS
a_1	b_1	c_1	72.31	a_2	b_1	c_1	76.03
a_1	b_2	c_1	74.05	a_2	b_2	c_1	75.56
a_1	b_3	c_1	73.03	a_2	b_3	c_1	75.85
a_1	b_4	c_1	74.25	a_2	b_4	c_1	76.70
a_1	b_5	c_1	74.99	a_2	b_5	c_1	80.46
a_1	b_6	c_1	75.54	a_2	b_6	c_1	73.92
a_1	b_1	c_2	78.85	a_2	b_1	c_2	79.50
a_1	b_2	c_2	78.81	a_2	b_2	c_2	78.90
a_1	b_3	c_2	78.05	a_2	b_3	c_2	78.93
a_1	b_4	c_2	78.83	a_2	b_4	c_2	78.63
a_1	b_5	c_2	79.08	a_2	b_5	c_2	79.08
a_1	b_6	c_2	78.99	a_2	b_6	c_2	78.80

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (FOR MEANS OF MACHINE UTILISATION

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	80.46	72.31	8.15	2.13	*
24 vs 2	80.46	73.03	7.43	2.13	*
24 vs 3	80.46	73.92	6.54	2.12	*
24 vs 4	80.46	74.05	6.41	2.12	*
24 vs 5	80.46	74.25	6.21	2.11	*
24 vs 6	80.46	74.99	5.47	2.10	*
24 vs 7	80.46	75.54	4.92	2.09	*
24 vs 8	80.46	75.56	4.90	2.08	*
24 vs 9	80.46	75.85	4.61	2.07	*
24 vs 10	80.46	76.03	4.43	2.06	*
24 vs 11	80.46	76.70	3.76	2.05	*
24 vs 12	80.46	78.05	2.41	2.03	*
24 vs 13	80.46	78.63	1.83	2.03	
24 vs 14	80.46	78.80	1.66	2.02	
24 vs 15	80.46	78.81	1.65	2.00	
24 vs 16	80.46	78.83	1.63	1.99	
24 vs 17	80.46	78.85	1.61	1.97	
24 vs 18	80.46	78.90	1.56	1.94	
24 vs 19	80.46	78.93	1.53	1.92	
24 vs 20	80.46	78.99	1.47	1.88	
24 vs 21	80.46	79.08	1.38	1.84	
24 vs 22	80.46	79.08	1.38	1.78	
24 vs 23	80.46	79.50	0.96	1.69	
23 vs 1	79.50	72.31	7.19	2.13	*
23 vs 2	79.50	73.03	6.47	2.12	*
23 vs 3	79.50	73.92	5.58	2.12	*
23 vs 4	79.50	74.05	5.45	2.11	*
23 vs 5	79.50	74.25	5.25	2.10	*
23 vs 6	79.50	74.99	4.51	2.09	*
23 vs 7	79.50	75.54	3.96	2.08	*
23 vs 8	79.50	75.56	3.94	2.07	*
23 vs 9	79.50	75.85	3.65	2.06	*
23 vs 10	79.50	76.03	3.47	2.05	*
23 vs 11	79.50	76.70	2.80	2.03	*
23 vs 12	79.50	78.05	1.45	2.03	
23 vs 13	79.50	78.63	0.87	2.02	
23 vs 14	79.50	78.80	0.70	2.00	
23 vs 15	79.50	78.81	0.69	1.99	
23 vs 16	79.50	78.83	0.67	1.97	
23 vs 17	79.50	78.85	0.65	1.94	
23 vs 18	79.50	78.90	0.60	1.92	
23 vs 19	79.50	78.93	0.57	1.88	
23 vs 20	79.50	78.99	0.51	1.84	

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 21	79.50	79.08	0.42	1.78	
23 vs 22	79.50	79.08	0.42	1.69	
22 vs 1	79.08	72.31	6.77	2.12	*
22 vs 2	79.08	73.03	6.05	2.12	*
22 vs 3	79.08	73.92	5.16	2.11	*
22 vs 4	79.08	74.05	5.03	2.10	*
22 vs 5	79.08	74.25	4.83	2.09	*
22 vs 6	79.08	74.99	4.09	2.08	*
22 vs 7	79.08	75.54	3.54	2.07	*
22 vs 8	79.08	75.56	3.52	2.06	*
22 vs 9	79.08	75.85	3.23	2.05	*
22 vs 10	79.08	76.03	3.05	2.03	*
22 vs 11	79.08	76.70	2.38	2.03	*
22 vs 12	79.08	78.05	1.03	2.02	
22 vs 13	79.08	78.63	0.45	2.00	
22 vs 14	79.08	78.80	0.28	1.99	
22 vs 15	79.08	78.81	0.27	1.97	
22 vs 16	79.08	78.83	0.25	1.94	
22 vs 17	79.08	78.85	0.23	1.92	
22 vs 18	79.08	78.90	0.18	1.88	
22 vs 19	79.08	78.93	0.15	1.84	
22 vs 20	79.08	78.99	0.09	1.78	
22 vs 21	79.08	79.08	0.00	1.69	
21 vs 1	79.08	72.31	6.77	2.12	*
21 vs 2	79.08	73.03	6.05	2.11	*
21 vs 3	79.08	73.92	5.16	2.10	*
21 vs 4	79.08	74.05	5.03	2.09	*
21 vs 5	79.08	74.25	4.83	2.08	*
21 vs 6	79.08	74.99	4.09	2.07	*
21 vs 7	79.08	75.54	3.54	2.06	*
21 vs 8	79.08	75.56	3.52	2.05	*
21 vs 9	79.08	75.85	3.23	2.03	*
21 vs 10	79.08	76.03	3.05	2.03	*
21 vs 11	79.08	76.70	2.38	2.02	*
21 vs 12	79.08	78.05	1.03	2.00	
21 vs 13	79.08	78.63	0.45	1.99	
21 vs 14	79.08	78.80	0.28	1.97	
21 vs 15	79.08	78.81	0.27	1.94	
21 vs 16	79.08	78.83	0.25	1.92	
21 vs 17	79.08	78.85	0.23	1.88	
21 vs 18	79.08	78.90	0.18	1.84	
21 vs 19	79.08	78.93	0.15	1.78	
21 vs 20	79.08	78.99	0.09	1.69	
20 vs 1	78.99	72.31	6.68	2.11	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
20 vs 2	78.99	73.03	5.96	2.10	*
20 vs 3	78.99	73.92	5.07	2.09	*
20 vs 4	78.99	74.05	4.94	2.08	*
20 vs 5	78.99	74.25	4.74	2.07	*
20 vs 6	78.99	74.99	4.00	2.06	*
20 vs 7	78.99	75.54	3.45	2.05	*
20 vs 8	78.99	75.56	3.43	2.03	*
20 vs 9	78.99	75.85	3.14	2.03	*
20 vs 10	78.99	76.03	2.96	2.02	*
20 vs 11	78.99	76.70	2.29	2.00	*
20 vs 12	78.99	78.05	0.94	1.99	
20 vs 13	78.99	78.63	0.36	1.97	
20 vs 14	78.99	78.80	0.19	1.94	
20 vs 15	78.99	78.81	0.18	1.92	
20 vs 16	78.99	78.83	0.16	1.88	
20 vs 17	78.99	78.85	0.14	1.84	
20 vs 18	78.99	78.90	0.09	1.78	
20 vs 19	78.99	78.93	0.06	1.69	
19 vs 1	78.93	72.31	6.62	2.10	*
19 vs 2	78.93	73.03	5.90	2.09	*
19 vs 3	78.93	73.92	5.01	2.08	*
19 vs 4	78.93	74.05	4.88	2.07	*
19 vs 5	78.93	74.25	4.68	2.06	*
19 vs 6	78.93	74.99	3.94	2.05	*
19 vs 7	78.93	75.54	3.39	2.03	*
19 vs 8	78.93	75.56	3.37	2.03	*
19 vs 9	78.93	75.85	3.08	2.02	*
19 vs 10	78.93	76.03	2.90	2.00	*
19 vs 11	78.93	76.70	2.23	1.99	*
19 vs 12	78.93	78.05	0.88	1.97	
19 vs 13	78.93	78.63	0.30	1.94	
19 vs 14	78.93	78.80	0.13	1.92	
19 vs 15	78.93	78.81	0.12	1.88	
19 vs 16	18.93	78.83	0.10	1.84	
19 vs 17	78.93	78.85	0.08	1.78	
19 vs 18	78.93	78.90	0.03	1.69	
18 vs 1	78.90	72.31	6.59	2.09	*
18 vs 2	78.90	73.03	5.87	2.08	*
18 vs 3	78.90	73.92	4.98	2.07	*
18 vs 4	78.90	74.05	4.85	2.06	*
18 vs 5	78.90	74.25	4.65	2.05	*
18 vs 6	78.90	74.99	3.91	2.03	*
18 vs 7	78.90	75.54	3.36	2.03	*
18 vs 8	78.90	75.56	3.34	2.02	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	78.90	75.85	3.05	2.00	*
18 vs 10	78.90	76.03	2.87	1.99	*
18 vs 11	78.90	76.70	2.20	1.97	*
18 vs 12	78.90	78.05	0.85	1.94	
18 vs 13	78.90	78.63	0.27	1.92	
18 vs 14	78.90	78.80	0.10	1.88	
18 vs 15	78.90	78.81	0.09	1.84	
18 vs 16	78.90	78.83	0.07	1.78	
18 vs 17	78.90	78.85	0.05	1.69	
17 vs 1	78.85	72.31	6.54	2.08	*
17 vs 2	78.85	73.03	5.82	2.07	*
17 vs 3	78.85	73.92	4.93	2.06	*
17 vs 4	78.85	74.05	4.80	2.05	*
17 vs 5	78.85	74.25	4.60	2.03	*
17 vs 6	78.85	74.99	3.86	2.03	*
17 vs 7	78.85	75.54	3.31	2.02	*
17 vs 8	78.85	75.56	3.29	2.00	*
17 vs 9	78.85	75.85	3.00	1.99	*
17 vs 10	78.85	76.03	2.82	1.97	*
17 vs 11	78.85	76.70	2.15	1.94	*
17 vs 12	78.85	78.05	o.80	1.92	
17 vs 13	78.85	78.63	0.22	1.88	
17 vs 14	78.85	78.80	0.05	1.84	
17 vs 15	78.55	78.81	0.04	1.78	
17 vs 16	78.85	78.83	0.02	1.69	
16 vs 1	78.83	72.31	6.52	2.07	*
16 vs 2	78.83	73.03	5.80	2.06	*
16 vs 3	78.83	73.92	4.91	2.05	*
16 vs 4	78.33	74.05	4.78	2.03	*
16 vs 5	78.83	74.25	4.58	2.03	*
16 vs 6	78.83	74.99	3.84	2.02	*
16 vs 7	78.83	75.54	3.29	2.00	*
16 vs 8	78.83	75.56	3.27	1.99	*
16 vs 9	78.83	75.85	2.98	1.97	*
16 vs 10	78.83	76.03	2.80	1.94	*
16 vs 11	78.83	76.70	2.13	1.92	*
16 vs 12	78.83	78.05	0.78	1.88	
16 vs 13	78.83	78.63	0.20	1.84	
16 vs 14	78.83	78.80	0.03	1.78	
16 vs 15	78.83	78.81	0.02	1.69	
15 vs 1	78.81	72.31	6.50	2.06	*
15 vs 2	78.81	73.03	5.78	2.05	*
15 vs 3	78.81	73.92	4.89	2.03	*
15 vs 4	78.81	74.05	4.76	2.03	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	78.81	74.25	4.56	2.02	*
15 vs 6	78.81	74.99	3.82	2.00	*
15 vs 7	78.81	75.54	3.27	1.99	*
15 vs 8	78.81	75.56	3.25	1.97	*
15 vs 9	78.81	75.85	2.96	1.94	*
15 vs 10	78.81	76.03	2.78	1.92	*
15 vs 11	78.81	76.70	2.11	1.88	*
15 vs 12	78.81	78.05	0.76	1.84	
15 vs 13	78.81	78.63	0.18	1.78	
15 vs 14	78.81	78.80	0.01	1.69	
14 vs 1	78.80	72.31	6.49	2.05	*
14 vs 2	78.80	73.03	5.77	2.03	*
14 vs 3	78.80	73.92	4.88	2.03	*
14 vs 4	78.80	74.05	4.75	2.02	*
14 vs 5	78.80	74.25	4.55	2.00	*
14 vs 6	28.80	74.99	3.81	1.99	*
14 vs 7	78.80	75.54	3.26	1.97	*
14 vs 8	78.80	75.56	3.24	1.94	*
14 vs 9	78.80	75.85	2.95	1.92	*
14 vs 10	78.80	76.03	2.77	1.88	*
14 vs 11	78.80	76.70	2.1o	1.84	*
14 vs 12	78.80	78.05	0.75	1.78	
14 vs 13	78.80	78.63	0.17	1.69	
13 vs 1	78.63	73.03	5.60	2.03	*
13 vs 2	78.63	73.03	5.60	2.03	*
13 vs 3	78.63	73.92	4.71	2.02	*
13 vs 4	78.63	74.05	4.58	2.00	*
13 vs 5	78.63	74.25	4.38	1.99	*
13 vs 6	78.63	74.99	3.64	1.97	*
13 vs 7	78.63	75.54	3.09	1.94	*
13 vs 8	78.63	75.56	3.07	1.92	*
13 vs 9	78.63	75.85	2.78	1.88	*
13 vs 10	78.63	76.03	2.60	1.84	*
13 vs 11	78.63	76.70	1.93	1.78	*
13 vs 12	78.63	78.05	0.58	1.69	
12 vs 1	78.05	72.31	5.74	2.03	*
12 vs 2	78.05	73.03	5.02	2.02	*
12 vs 3	78.05	73.92	4.13	2.00	*
12 vs 4	78.05	74.05	4.00	1.99	*
12 vs 5	78.05	74.25	3.80	1.97	*
12 vs 6	78.05	74.99	3.06	1.94	*
12 vs 7	78.05	75.54	2.51	1.92	*
12 vs 8	78.05	75.56	2.49	1.88	*
12 vs 9	78.05	75.85	2.20	1.84	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	78.81	74.25	4.56	2.02	*
15 vs 6	78.81	74.99	3.82	2.00	*
15 vs 7	78.81	75.54	3.27	1.99	*
15 vs 8	78.81	75.56	3.25	1.97	*
15 vs 9	78.81	75.85	2.96	1.94	*
15 vs 10	78.81	76.03	2.78	1.92	*
15 vs 11	78.81	76.70	2.11	1.88	*
15 vs 12	78.81	78.05	0.76	1.84	
15 vs 13	78.81	78.63	0.18	1.78	
15 vs 14	78.81	78.80	0.01	1.69	
14 vs 1	78.80	72.31	6.49	2.05	*
14 vs 2	78.80	73.03	5.77	2.03	*
14 vs 3	78.80	73.92	4.88	2.03	*
14 vs 4	78.80	74.05	4.75	2.02	*
14 vs 5	78.80	74.25	4.55	2.00	*
14 vs 6	28.80	74.99	3.81	1.99	*
14 vs 7	78.80	75.54	3.26	1.97	*
14 vs 8	78.80	75.56	3.24	1.94	*
14 vs 9	78.80	75.85	2.95	1.92	*
14 vs 10	78.80	76.03	2.77	1.88	*
14 vs 11	78.80	76.70	2.10	1.84	*
14 vs 12	78.80	78.05	0.75	1.78	
14 vs 13	78.80	78.63	0.17	1.69	
13 vs 1	78.63	73.03	5.60	2.03	*
13 vs 2	78.63	73.03	5.60	2.03	*
13 vs 3	78.63	73.92	4.71	2.02	*
13 vs 4	78.63	74.05	4.58	2.00	*
13 vs 5	78.63	74.25	4.38	1.99	*
13 vs 6	78.63	74.99	3.64	1.97	*
13 vs 7	78.63	75.54	3.09	1.94	*
13 vs 8	78.63	75.56	3.07	1.92	*
13 vs 9	78.63	75.85	2.78	1.88	*
13 vs 10	78.63	76.03	2.60	1.84	*
13 vs 11	78.63	76.70	1.93	1.78	*
13 vs 12	78.63	78.05	0.58	1.69	
12 vs 1	78.05	72.31	5.74	2.03	*
12 vs 2	78.05	73.03	5.02	2.02	*
12 vs 3	78.05	73.92	4.13	2.00	*
12 vs 4	78.05	74.05	4.00	1.99	*
12 vs 5	78.05	74.25	3.80	1.97	*
12 vs 6	78.05	74.99	3.06	1.94	*
12 vs 7	78.05	75.54	2.51	1.92	*
12 vs 8	78.05	75.56	2.49	1.88	*
12 vs 9	78.05	75.85	2.20	1.84	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	78.05	76.03	2.02	1.78	*
12 vs 11	78.05	76.70	1.35	1.69	
11 vs 1	76.70	72.31	4.39	2.02	*
11 vs 2	76.70	73.03	3.67	2.00	*
11 vs 3	76.70	73.92	2.76	1.99	*
11 vs 4	76.70	74.05	2.65	1.97	*
11 vs 5	76.70	74.25	2.45	1.94	*
11 vs 6	76.70	74.99	1.71	1.92	
11 vs 7	76.70	75.54	1.16	1.88	
11 vs 8	76.70	75.56	1.14	1.84	
11 vs 9	76.70	75.85	0.85	1.78	
11 vs 10	76.70	76.03	0.67	1.69	
10 vs 1	76.03	72.31	3.72	2.00	*
10 vs 2	76.03	73.03	3.00	1.99	*
10 vs 3	76.03	73.92	2.11	1.97	*
10 vs 4	76.03	74.05	1.98	1.94	*
10 vs 5	76.03	74.25	1.78	1.92	
10 vs 6	76.03	74.99	1.04	1.88	
10 vs 7	76.03	75.54	0.49	1.84	
10 vs 8	76.03	75.56	0.47	1.78	
10 vs 9	76.03	75.85	0.18	1.69	
9 vs 1	75.85	72.31	3.54	1.99	*
9 vs 2	75.85	73.03	2.82	1.97	*
9 vs 3	75.85	73.92	1.93	1.94	
9 vs 4	75.85	74.05	1.80	1.92	
9 vs 5	75.85	74.25	1.60	1.88	
9 vs 6	75.85	74.99	0.86	1.84	
9 vs 7	75.85	75.54	0.31	1.78	
9 vs 8	75.85	75.56	0.29	1.69	
8 vs 1	75.56	72.31	3.25	1.97	*
8 vs 2	75.56	73.03	2.53	1.94	*
8 vs 3	75.56	73.92	1.64	1.92	
8 vs 4	75.56	74.05	1.51	1.88	
8 vs 5	75.56	74.25	1.31	1.84	
8 vs 6	75.56	74.99	0.57	1.78	
8 vs 7	75.56	75.54	0.02	1.69	
7 vs 1	75.54	72.31	3.23	1.94	*
7 vs 2	75.54	73.03	2.51	1.92	*
7 vs 3	75.54	73.92	1.62	1.88	
7 vs 4	75.54	74.05	1.49	1.84	
7 vs 5	75.54	74.25	1.29	1.78	
7 vs 6	75.54	74.99	0.55	1.69	
6 vs 1	74.99	72.31	2.68	1.92	*
6 vs 2	74.99	73.03	1.96	1.88	*

TABLE E.37 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A, B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	74.99	73.92	1.07	1.84	
6 vs 4	74.99	74.05	0.94	1.78	
6 vs 5	74.99	74.25	0.74	1.69	
5 vs 1	74.25	72.31	1.94	1.88	*
5 vs 2	74.25	73.03	1.22	1.84	
5 vs 3	74.25	73.92	0.33	1.78	
5 vs 4	74.25	74.05	0.20	1.69	
4 vs 1	74.05	72.31	1.74	1.84	
4 vs 2	74.05	73.03	1.02	1.78	
4 vs 3	74.05	73.92	0.13	1.69	
3 vs 1	73.92	72.31	1.61	1.78	
3 vs 2	73.92	73.03	0.89	1.69	
2 vs 1	73.03	72.31	0.72	1.69	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.38 MEANS OF INTERACTION BETWEEN FACTORS B, C, AND D FOR MEAN MACHINE UTILISATION

FACTOR LEVEL			MEANS	FACTOR LEVEL			MEANS
b_j	c_k	d_l		b_j	c_k	d_l	
b_1	c_1	d_1	72.22	b_1	c_2	d_1	79.46
b_2	c_1	d_1	74.55	b_2	c_2	d_1	78.25
b_3	c_1	d_1	73.09	b_3	c_2	d_1	78.44
b_4	c_1	d_1	74.87	b_4	c_2	d_1	78.97
b_5	c_1	d_1	79.40	b_5	c_2	d_1	78.56
b_6	c_1	d_1	72.98	b_6	c_2	d_1	79.48
b_1	c_1	d_2	76.12	b_1	c_2	d_2	79.06
b_2	c_1	d_2	76.06	b_2	c_2	d_2	79.46
b_3	c_1	d_2	74.88	b_3	c_2	d_2	78.53
b_4	c_1	d_2	78.09	b_4	c_2	d_2	78.49
b_5	c_1	d_2	76.05	b_5	c_2	d_2	79.60
b_6	c_1	d_2	76.48	b_6	c_2	d_2	78.31

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (FOR MEANS OF MACHINE UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
24 vs 1	79.60	72.22	7.38	2.13	*
24 vs 2	79.60	72.98	6.62	2.13	*
24 vs 3	79.60	73.09	6.51	2.12	*
24 vs 4	79.60	74.55	5.05	2.12	*
24 vs 5	79.60	74.87	4.73	2.11	*
24 vs 6	79.60	74.88	4.72	2.10	*
24 vs 7	79.60	76.05	3.55	2.09	*
24 vs 8	79.60	76.06	3.54	2.08	*
24 vs 9	79.60	76.09	3.51	2.07	*
24 vs 10	79.60	76.12	3.48	2.06	*
24 vs 11	79.60	76.48	3.12	2.05	*
24 vs 12	79.60	78.25	1.35	2.03	
74 vs 13	79.60	78.31	1.29	2.03	
24 vs 14	79.60	78.44	1.16	2.02	
24 vs 15	79.60	78.49	1.11	2.00	
24 vs 16	79.60	78.53	1.07	1.99	
24 vs 17	79.60	78.56	1.04	1.97	
24 vs 18	79.60	78.97	0.63	1.94	
24 vs 19	79.60	79.06	0.54	1.92	
24 vs 20	79.60	79.40	0.20	1.88	
24 vs 21	79.60	79.46	0.14	1.84	
24 vs 22	79.60	79.46	0.14	1.78	
24 vs 23	79.60	79.48	0.12	1.69	
23 vs 1	79.48	72.22	7.26	2.13	*
23 vs 2	79.48	72.98	6.50	2.12	*
23 vs 3	79.48	73.09	6.39	2.12	*
23 vs 4	79.48	74.55	4.93	2.11	*
23 vs 5	79.48	74.87	4.61	2.10	*
23 vs 6	79.48	74.88	4.60	2.09	*
23 vs 7	79.48	76.05	3.43	2.08	*
23 vs 8	79.48	76.06	3.42	2.07	*
23 vs 9	79.48	76.09	3.39	2.06	*
23 vs 10	79.48	76.12	3.36	2.05	*
23 vs 11	79.48	76.48	3.00	2.03	*
23 vs 12	79.48	78.25	1.23	2.03	
23 vs 13	79.48	78.31	1.17	2.02	
23 vs 14	79.48	78.44	1.04	2.00	
23 vs 15	79.48	78.49	0.99	1.99	
23 vs 16	79.48	78.53	0.95	1.97	
23 vs 17	79.48	78.56	0.92	1.94	
23 vs 18	79.48	78.97	0.51	1.92	
23 vs 19	79.48	79.06	0.42	1.88	
23 vs 20	79.48	79.40	0.08	1.84	

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
23 vs 1	79.48	79.46	0.02	1.78	
23 vs 2	79.48	79.46	0.02	1.69	
22 vs 1	79.46	72.22	7.24	2.12	*
22 vs 2	79.46	72.98	6.48	2.12	*
22 vs 3	79.46	73.09	6.37	2.11	*
22 vs 4	79.46	74.55	4.91	2.10	*
22 vs 5	79.46	74.87	4.59	2.09	*
22 vs 6	79.46	74.88	4.58	2.08	*
22 vs 7	79.46	76.05	3.41	2.07	*
22 vs 8	79.46	76.06	3.40	2.06	*
22 vs 9	79.46	76.09	3.37	2.05	*
22 vs 10	79.46	76.12	3.34	2.03	*
22 vs 11	79.46	76.48	2.98	2.03	*
22 vs 12	79.46	78.25	1.21	2.02	
22 vs 13	79.46	78.31	1.15	2.00	
22 vs 14	79.46	78.44	1.02	1.99	
22 vs 15	79.46	78.49	0.97	1.97	
22 vs 16	79.46	78.53	0.93	1.94	
22 vs 17	79.46	78.56	0.90	1.92	
22 vs 18	79.46	78.97	0.49	1.88	
22 vs 19	79.46	79.06	0.40	1.84	
22 vs 20	79.46	79.40	0.06	1.78	
22 vs 21	79.46	79.46	0.00	1.69	
21 vs 1	79.46	72.22	7.24	2.12	*
21 vs 2	79.46	72.98	6.48	2.11	*
21 vs 3	79.46	73.09	6.37	2.10	*
21 vs 4	79.46	74.55	4.91	2.09	*
21 vs 5	79.46	74.87	4.59	2.08	*
21 vs 6	79.46	74.88	4.58	2.07	*
21 vs 7	79.46	76.05	3.41	2.06	*
21 vs 8	79.46	76.06	3.40	2.05	*
21 vs 9	79.46	76.09	3.37	2.03	*
21 vs 10	79.46	76.12	3.34	2.03	*
21 vs 11	79.46	76.48	2.98	2.02	*
21 vs 12	79.46	78.25	1.21	2.00	
21 vs 13	79.46	78.31	1.15	1.99	
21 vs 14	79.46	78.44	1.02	1.97	
21 vs 15	79.46	78.49	0.97	1.94	
21 vs 16	79.46	78.53	0.93	1.92	
21 vs 17	79.46	78.56	0.90	1.88	
21 vs 18	79.46	78.97	0.49	1.84	
21 vs 19	79.46	79.06	0.40	1.78	
21 vs 10	79.46	79.40	0.06	1.69	
20 vs 1	79.40	72.22	7.18	2.11	*

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
20 vs 2	79.40	72.96	6.42	2.10	*
20 vs 3	79.40	73.09	6.31	2.09	*
20 vs 4	79.40	74.55	4.85	2.08	*
20 vs 5	79.40	74.87	4.53	2.07	*
20 vs 6	79.40	74.88	4.52	2.06	*
20 vs 7	79.40	76.05	3.35	2.05	*
20 vs 8	79.40	76.06	3.34	2.03	*
20 vs 9	79.40	76.09	3.31	2.03	*
20 vs 10	79.40	76.12	3.28	2.02	*
21 vs 11	79.40	76.48	2.92	2.00	*
20 vs 12	79.40	78.25	1.15	1.99	
20 vs 13	79.40	78.31	1.09	1.97	
20 vs 14	79.40	78.44	0.96	1.94	
20 vs 15	79.40	78.49	0.91	1.92	
20 vs 16	79.40	78.53	0.87	1.88	
20 vs 17	79.40	78.56	0.84	1.84	
20 vs 18	79.40	78.97	0.43	1.78	
20 vs 19	79.40	79.06	0.34	1.69	
19 vs 1	79.06	72.22	6.84	2.10	*
19 vs 2	79.06	72.98	6.08	2.09	*
19 vs 3	79.06	73.09	5.97	2.08	*
19 vs 4	79.06	74.55	4.51	2.07	*
19 vs 5	79.06	74.87	4.19	2.06	*
19 vs 6	79.06	74.88	4.18	2.05	*
19 vs 7	79.06	76.05	3.01	2.03	*
19 vs 8	79.06	76.06	3.00	2.03	*
19 vs 9	79.06	76.09	2.97	2.02	*
19 vs 10	79.06	76.12	2.94	2.00	*
19 vs 11	79.06	76.48	2.58	1.99	*
19 vs 12	79.06	78.25	0.81	1.97	
19 vs 13	79.06	78.31	0.75	1.94	
19 vs 14	79.06	78.44	0.62	1.92	
19 vs 15	79.06	78.49	0.57	1.88	
19 vs 16	79.06	78.53	0.53	1.84	
19 vs 17	79.06	78.56	0.50	1.78	
19 vs 18	79.06	78.97	0.09	1.69	
18 vs 1	78.97	72.22	6.75	2.09	*
18 vs 2	78.97	72.98	5.99	2.08	*
18 vs 3	78.97	73.09	5.88	2.07	*
18 vs 4	78.97	74.55	4.42	2.06	*
18 vs 5	78.97	74.87	4.10	2.05	*
18 vs 6	78.97	74.88	4.09	2.03	*
18 vs 7	78.97	76.05	2.92	2.03	*
18 vs 8	78.97	76.06	2.91	2.02	*

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
18 vs 9	78.97	76.09	2.88	2.00	*
18 vs 10	78.97	76.12	2.85	1.99	*
18 vs 11	78.97	76.48	2.49	1.97	*
18 vs 12	78.97	78.25	0.72	1.94	
18 vs 13	78.97	78.31	0.66	1.92	
18 vs 14	78.97	78.44	0.53	1.88	
18 vs 15	78.97	78.49	0.48	1.84	
18 vs 16	78.97	78.53	0.44	1.78	
18 vs 17	78.97	78.56	0.41	1.69	
17 vs 1	78.56	72.22	6.34	2.08	*
17 vs 2	78.56	72.98	5.58	2.07	*
17 vs 3	78.56	73.09	5.47	2.06	*
17 vs 4	78.56	74.55	4.01	2.05	*
17 vs 5	78.56	74.87	3.69	2.03	*
17 vs 6	78.56	74.88	3.68	2.03	*
17 vs 7	78.56	76.05	2.51	2.02	*
17 vs 8	78.56	76.06	2.50	2.00	*
17 vs 9	78.56	76.09	2.47	1.99	*
17 vs 10	78.56	76.12	2.44	1.97	*
17 vs 11	78.56	76.48	2.08	1.94	*
17 vs 12	78.56	78.25	0.31	1.92	
17 vs 13	78.56	78.31	0.25	1.88	
17 vs 14	78.56	78.44	0.12	1.84	
17 vs 15	78.56	78.49	0.07	1.78	
17 vs 16	78.56	78.53	0.03	1.69	
16 vs 1	78.53	72.22	6.31	2.07	*
16 vs 2	78.53	72.98	5.55	2.06	*
16 vs 3	78.53	73.09	5.44	2.05	*
16 vs 4	78.53	74.55	3.98	2.03	*
16 vs 5	78.53	74.87	3.66	2.03	*
16 vs 6	78.53	74.88	3.65	2.02	*
16 vs 7	78.53	76.05	2.48	2.00	*
16 vs 8	78.53	76.06	2.47	1.99	*
16 vs 9	78.53	76.09	2.44	1.97	*
16 vs 10	78.53	76.12	2.41	1.94	*
16 vs 11	78.53	76.48	2.05	1.92	*
16 vs 12	78.53	78.25	0.28	1.88	
16 vs 13	78.53	78.31	0.22	1.84	
16 vs 14	78.53	78.44	0.09	1.78	
16 vs 15	78.53	78.49	0.04	1.69	
15 vs 1	78.49	72.22	6.17	2.06	*
15 vs 2	78.49	72.98	5.51	2.05	*
15 vs 3	78.49	73.09	5.40	2.03	*
15 vs 4	78.49	74.55	3.94	2.03	*

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
15 vs 5	78.49	74.87	3.62	2.02	*
15 vs 6	78.49	74.88	3.61	2.00	*
15 vs 7	78.49	76.05	2.44	1.99	*
15 vs 8	78.49	76.06	2.43	1.97	*
15 vs 9	78.49	76.09	2.40	1.94	*
15 vs 10	78.49	76.12	2.37	1.92	*
15 vs 11	78.49	76.48	2.01	1.88	*
15 vs 12	78.49	78.25	0.24	1.84	
15 vs 13	78.49	78.31	0.18	1.78	
15 vs 14	78.49	78.44	0.05	1.69	
14 vs 1	78.44	72.22	6.22	2.05	*
14 vs 2	78.44	72.98	5.46	2.03	*
14 vs 3	78.44	73.09	5.35	2.03	*
14 vs 4	78.44	74.55	3.89	2.02	*
14 vs 5	78.44	74.87	3.57	2.00	*
14 vs 6	78.44	74.88	3.56	1.99	*
14 vs 7	78.44	76.05	2.39	1.97	*
14 vs 8	78.44	76.06	2.38	1.94	*
14 vs 9	78.44	76.09	2.35	1.92	*
14 vs 10	78.44	76.12	2.32	1.88	*
14 vs 11	78.44	76.48	1.96	1.84	*
14 vs 12	78.44	78.25	0.19	1.78	
14 vs 13	78.44	78.31	0.13	1.69	
13 vs 1	78.31	72.22	6.09	2.03	*
13 vs 2	78.31	72.98	5.33	2.03	*
13 vs 3	78.31	73.09	5.22	2.02	*
13 vs 4	78.31	74.55	3.76	2.00	*
13 vs 5	78.31	74.87	3.44	1.99	*
13 vs 6	78.31	74.88	3.43	1.97	*
13 vs 7	78.31	76.05	2.26	1.94	*
13 vs 8	78.31	76.06	2.25	1.92	*
13 vs 9	78.31	76.09	2.22	1.88	*
13 vs 10	78.31	76.12	2.19	1.84	*
13 vs 11	78.31	76.48	1.83	1.78	*
13 vs 12	78.31	78.25	0.06	1.69	
12 vs 1	78.25	72.22	6.03	2.03	*
12 vs 2	78.25	72.98	5.27	2.02	*
13 vs 3	78.25	73.09	5.16	2.00	*
12 vs 4	78.25	74.55	3.70	1.99	*
12 vs 5	78.25	74.87	3.38	1.97	*
12 vs 6	78.25	74.88	3.37	1.94	*
12 vs 7	78.25	76.05	2.20	1.92	*
12 vs 8	78.25	76.06	2.19	1.88	*
12 vs 9	78.25	76.09	2.16	1.84	*

TABLE E. 39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 10	78.25	76.12	2.13	1.78	*
12 vs 11	78.25	76.48	1.77	1.69	*
11 vs 1	76.48	72.22	4.26	2.02	*
11 vs 2	76.48	72.98	3.50	2.00	*
11 vs 3	76.48	73.09	3.39	1.99	*
11 vs 4	76.48	74.55	1.93	1.97	
11 vs 5	76.48	74.87	1.61	1.94	
11 vs 6	76.48	74.88	1.60	1.92	
11 vs 7	76.48	76.05	0.43	1.88	
11 vs 8	76.48	76.06	0.42	1.84	
11 vs 9	76.48	76.09	0.39	1.78	
11 vs 10	76.48	76.12	0.36	1.69	
10 vs 1	76.12	72.22	3.90	2.00	*
10 vs 2	76.12	72.98	3.14	1.99	*
10 vs 3	76.12	73.09	3.03	1.97	*
10 vs 4	76.12	74.55	1.57	1.94	
10 vs 5	76.12	74.87	1.25	1.92	
10 vs 6	76.12	74.88	1.24	1.88	
10 vs 7	76.12	76.05	0.07	1.84	
10 vs 8	76.12	76.06	0.06	1.78	
10 vs 9	76.12	76.09	0.03	1.69	
9 vs 1	76.09	72.22	3.87	1.99	*
9 vs 2	76.09	72.98	3.11	1.97	*
9 vs 3	76.09	73.09	3.00	1.94	*
9 vs 4	76.09	74.55	1.54	1.92	
9 vs 5	76.09	74.87	1.22	1.88	
9 vs 6	76.09	74.88	1.21	1.84	
9 vs 7	76.09	76.05	0.04	1.78	
9 vs 8	76.09	76.06	0.03	1.69	
8 vs 1	76.06	72.22	3.84	1.97	*
8 vs 2	76.06	72.98	3.08	1.94	*
8 vs 3	76.06	73.09	2.97	1.92	*
8 vs 4	76.06	74.55	1.51	1.88	
8 vs 5	76.06	74.87	1.19	1.84	
8 vs 6	76.06	74.88	1.18	1.78	
8 vs 7	76.06	76.05	0.01	1.69	
7 vs 1	76.05	72.22	3.83	1.94	*
7 vs 2	76.05	72.98	3.07	1.92	*
7 vs 3	76.05	73.09	2.96	1.88	*
7 vs 4	76.05	74.55	1.50	1.84	
7 vs 5	76.05	74.87	1.18	1.78	
7 vs 6	76.05	74.88	1.17	1.69	
6 vs 1	74.88	72.22	2.66	1.92	*
6 vs 2	74.88	72.98	1.90	1.88	*

TABLE E.39 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B, C AND D (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
6 vs 3	74.88	73.09	1.79	1.84	
6 vs 4	74.88	74.55	0.33	1.78	
6 vs 5	74.88	74.87	0.01	1.69	
5 vs 1	74.87	72.22	2.65	1.88	*
5 vs 2	74.87	72.98	1.89	1.84	*
5 vs 3	74.87	73.09	1.78	1.78	*
5 vs 4	74.87	74.55	0.32	1.69	
4 vs 1	74.55	72.22	2.33	1.84	*
4 vs 2	74.55	72.98	1.57	1.78	
4 vs 3	74.55	73.09	1.46	1.69	
3 vs 1	73.09	72.22	0.87	1.78	
3 vs 2	73.09	72.98	0.11	1.69	
2 vs 1	72.98	72.22	0.76	1.69	

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.40 MEANS OF INTERACTION BETWEEN FACTORS A AND C FOR MEAN OPERATOR UTILISATION

FACTOR LEVEL a_i	c_k	MEANS	FACTOR LEVEL a_i	c_k	MEANS
a_1	c_1	82.31	a_2	c_1	83.22
a_1	c_2	85.90	a_2	c_2	85.83

TABLE E.41 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS A AND C (FOR MEANS OF OPERATOR UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
4 vs 1	85.90	82.31	3.59	0.93	*
4 vs 2	85.90	83.22	2.68	0.90	*
4 vs 3	85.90	85.83	0.07	0.85	
3 vs 1	85.83	82.31	3.52	0.90	*
3 vs 2	85.83	83.22	2.61	0.85	*
2 vs 1	83.22	82.31	0.91	0.85	*

* = Significant at the 0.05 level
LSR = Least significant range.

TABLE E.42 MEANS OF INTERACTION BETWEEN FACTORS B AND C FOR MEAN OPERATOR UTILISATION

FACTOR LEVEL b_j	c_k	MEANS	FACTOR LEVEL b_j	c_k	MEANS
b_1	c_1	82.52	b_1	c_2	86.13
b_2	c_1	83.44	b_2	c_2	85.64
b_3	c_1	83.32	b_3	c_2	84.77
b_4	c_1	82.57	b_4	c_2	86.58
b_5	c_1	81.98	b_5	c_2	85.95
b_6	c_1	82.79	b_6	c_2	86.12

TABLE E.43 COMPARISONOF MEANS OF INTERACTION BETWEEN FACTORS B AND C (FOR MEANS OF OPERATOR UTILISATION)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
12 vs 1	86.58	81.98	4.60	1.02	*
12 vs 2	86.58	82.52	4.06	1.02	*
12 vs 3	86.58	82.57	4.01	1.01	*
12 vs 4	86.58	82.79	3.79	1.00	*
12 vs 5	86.58	83.32	3.26	0.99	*
12 vs 6	86.58	83.44	3.14	0.98	*
12 vs 7	86.58	84.77	1.81	0.97	*
12 vs 8	86.58	85.64	0.94	0.94	
12 vs 9	86.58	85.95	0.63	0.93	
12 vs 10	86.58	86.12	0.46	0.90	
12 vs 11	86.58	86.13	0.45	0.85	
11 vs 1	86.13	81.98	4.15	1.02	*
11 vs 2	86.13	82.52	3.61	1.01	*
11 vs 3	86.13	82.57	3.56	1.00	*
11 vs 4	86.13	82.79	3.34	0.99	*
11 vs 5	86.13	83.32	2.81	0.98	*
11 vs 6	86.13	83.44	2.69	0.97	*
11 vs 7	86.13	84.77	1.36	0.95	
11 vs 8	86.13	85.64	0.49	0.93	
11 vs 9	86.13	85.95	0.18	0.90	
11 vs 10	86.13	86.12	0.01	0.85	
10 vs 1	86.12	81.98	4.14	1.01	*
10 vs 2	86.12	82.52	3.60	1.00	*
10 vs 3	86.12	82.57	3.55	0.99	*
10 vs 4	86.12	82.79	3.33	0.98	*
10 vs 5	86.12	83.32	2.80	0.97	*
10 vs 6	86.12	83.44	2.68	0.95	*
10 vs 7	86.12	84.77	1.35	0.93	*
10 vs 8	86.12	85.64	0.48	1.90	
10 vs 9	86.12	85.95	0.17	0.85	
9 vs 1	85.95	81.98	3.97	1.00	*
9 vs 2	85.95	82.52	3.43	0.99	*
9 vs 3	85.95	82.57	3.38	0.98	*
9 vs 4	85.95	82.79	3.16	0.97	*
9 vs 5	85.95	83.32	2.63	0.95	*
9 vs 6	85.95	83.44	2.51	0.93	*
9 vs 7	85.95	84.77	1.18	0.90	*
9 vs 8	85.95	85.64	0.31	0.85	
8 vs 1	85.64	81.98	3.66	0.99	*
8 vs 2	85.64	82.52	3.12	0.98	*
8 vs 3	85.64	82.57	3.07	0.97	*
8 vs 4	85.64	82.79	2.85	0.95	*
8 vs 5	85.64	83.32	2.32	0.93	*

TABLE E.43 COMPARISON OF MEANS OF INTERACTION BETWEEN FACTORS B AND C (continued)

COMPARISON m vs n	Y(m)	Y(n)	DIFFERENCE	LSR	SIGN
8 vs 6	85.64	83.44	2.20	0.90	*
8 vs 7	85.64	84.77	0.87	0.85	*
7 vs 1	84.77	81.98	2.79	0.98	*
7 vs 2	84.77	82.52	2.25	0.97	*
7 vs 3	84.77	82.57	2.20	0.95	*
7 vs 4	84.77	82.79	1.98	0.93	*
7 vs 5	84.77	83.32	1.45	0.90	*
7 vs 6	84.77	83.44	1.33	0.85	*
6 vs 1	83.44	81.98	1.46	0.97	*
6 vs 2	83.44	82.52	0.92	0.95	
6 vs 3	83.44	82.57	0.87	0.93	
6 vs 4	83.44	82.79	0.65	0.90	
6 vs 5	83.44	83.32	0.12	0.85	
5 vs 1	83.32	81.98	1.34	0.95	*
5 vs 2	83.32	82.52	0.80	0.93	
5 vs 3	83.32	82.57	0.75	0.90	
5 vs 4	83.32	82.79	0.53	0.85	
4 vs 1	82.79	81.98	0.81	0.93	
4 vs 2	82.79	82.52	0.27	0.90	
4 vs 3	82.79	82.57	0.22	0.85	
3 vs 1	82.57	81.98	0.59	0.90	
3 vs 2	82.57	82.52	0.05	0.85	
2 vs 1	82.52	81.98	0.54	0.85	

* = Significant at the 0.05 level
LSR = Least significant range.

Table E.44. Significant Ranges for Duncan's Multiple Range Test

$r_{.05}(p,f)$

f	p = 2	3	4	5	6	7	8	9	10	20	50	100
1	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0	18.0
2	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09	6.09
3	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50	4.50
4	3.93	4.01	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02	4.02
5	3.64	3.74	3.79	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83	3.83
6	3.46	3.58	3.64	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68
7	3.35	3.47	3.54	3.58	3.60	3.61	3.61	3.61	3.61	3.61	3.61	3.61
8	3.26	3.39	3.47	3.52	3.55	3.56	3.56	3.56	3.56	3.56	3.56	3.56
9	3.20	3.34	3.41	3.47	3.50	3.52	3.52	3.52	3.52	3.52	3.52	3.52
10	3.15	3.30	3.37	3.43	3.46	3.47	3.47	3.47	3.47	3.48	3.48	3.48
11	3.11	3.27	3.35	3.39	3.43	3.44	3.45	3.46	3.46	3.48	3.48	3.48
12	3.08	3.23	3.33	3.36	3.40	3.42	3.44	3.44	3.46	3.48	3.48	3.48
13	3.06	3.21	3.30	3.35	3.38	3.41	3.42	3.44	3.45	3.47	3.47	3.47
14	3.03	3.18	3.27	3.33	3.37	3.39	3.41	3.42	3.44	3.47	3.47	3.47
15	3.01	3.16	3.25	3.31	3.36	3.38	3.40	3.42	3.43	3.47	3.47	3.47
16	3.00	3.15	3.23	3.30	3.34	3.37	3.39	3.41	3.43	3.47	3.47	3.47
17	2.98	3.13	3.22	3.28	3.33	3.36	3.38	3.40	3.42	3.47	3.47	3.47
18	2.97	3.12	3.21	3.27	3.32	3.35	3.37	3.39	3.41	3.47	3.47	3.47
19	2.96	3.11	3.19	3.26	3.31	3.35	3.37	3.39	3.41	3.47	3.47	3.47
20	2.95	3.10	3.18	3.25	3.30	3.34	3.36	3.38	3.40	3.47	3.47	3.47
30	2.89	3.04	3.12	3.20	3.25	3.29	3.32	3.35	3.37	3.47	3.47	3.47
40	2.86	3.01	3.10	3.17	3.22	3.27	3.30	3.33	3.35	3.47	3.47	3.47
60	2.83	2.98	3.08	3.14	3.20	3.24	3.28	3.31	3.33	3.47	3.48	3.48
100	2.80	2.95	3.05	3.12	3.18	3.22	3.26	3.29	3.32	3.47	3.53	3.53
∞	2.77	2.92	3.02	3.09	3.15	3.19	3.23	3.26	3.29	3.47	3.61	3.67

f = degrees of freedom.

E.2 DISCUSSION ON THE RESULT OF THE COMPARISON TEST

Based on the results of the comparison test of the means of treatments which have been carried out in Section E.1, the following discussion on the result is presented.

E.2.1 Means of RMS of tardiness

E.2.1.1 AB Interaction

A plot of the first order interaction between factor A, due date assignment method, and factor B, priority rule, based on the data in Table E.1 is shown in Fig. E.1. This significant interaction is indicated by the lack of parallelism of the lines. Based on the significant test result of means of AB interaction for RMS of tardiness which is shown in Table E.3, it can be proved that there is significant difference in RMS of tardiness between STR priority rule and the other rules for any of the due date assignment methods tested. In addition, the combinations involving the STR priority rule with level of factor A yields in s significantly lower mean RMS of tardiness and, therefore, are the best performers compared with the other combinations. Further, the combinations of TWC/FCFS and TWC/SIOT produce a significantly higher mean RMS of tardiness than the other combinations and do not differ significantly in terms of this performance. However, the combination of TWC/FCFS produces a higher RMS of tardiness.

E.2.1.2 BC Interaction

The first order interaction between factor B, priority rule, and factor C, process batch method, is illustrated in Fig. E.2. The illustration is based

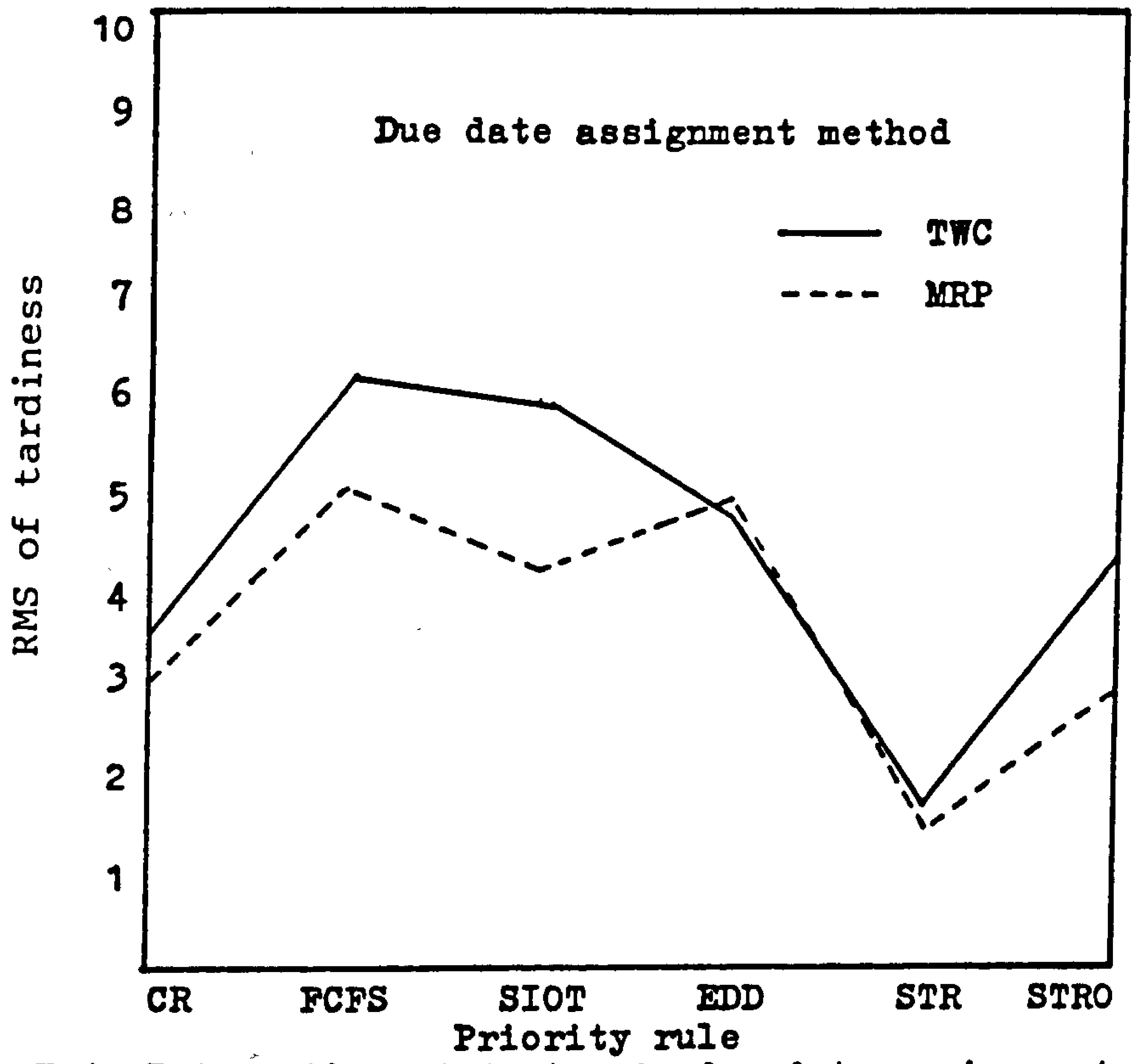


Fig.E.1. Interaction of factor A, due date assignment method, and factor B, priority rule in terms of RMS of tardiness.

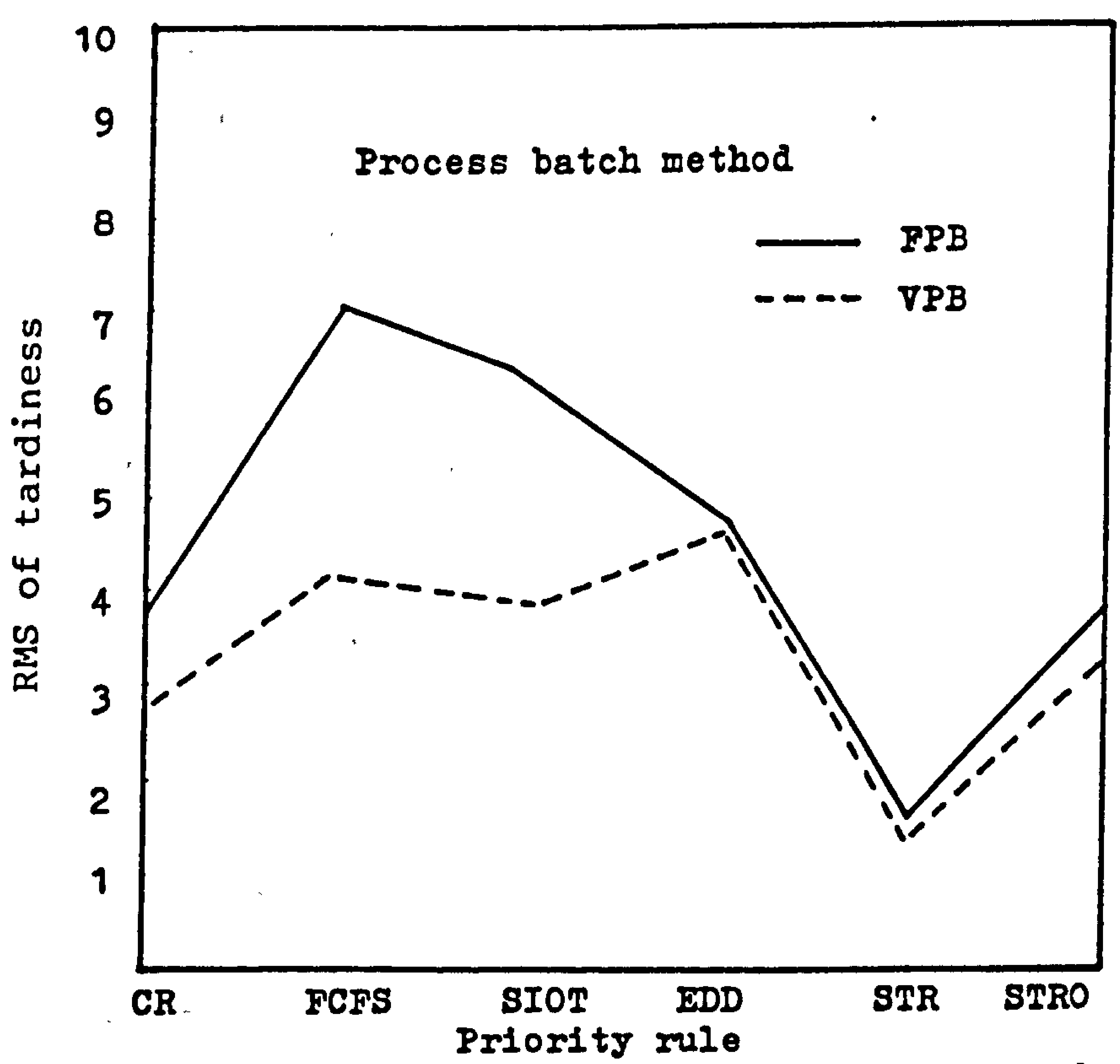


Fig.E.2. Interaction of factor B, priority rule, and factor C, process batch method in terms of RMS of tardiness.

on means of BC interaction in Table E.4. From this figure and the comparison test result of means of BC interaction in Table E.5, it can be shown and proved that there is no significant difference in RMS of tardiness between the combinations of STR/FPB and STR/VPB. Further, both these combinations produce a lower RMS of tardiness compared with the other combinations. Meanwhile, the combinations of FCFS/FPB and SIOT/FPB perform significantly worse than the other combinations. The worst result was obtained when FCFS is combined with FPB.

E.2.1.3 BD Interaction

Fig. E.3 based on the data in Table E.6 illustrates the interaction between factor B, priority rule, and factor D, operatior reassignment policy. Fig. E.3 and the comparison test result of means of BD interaction in Table E.7 show that the combination of FCFS and COR is significantly different in mean RMS of tardiness from the other combinations except with combination of SIOT and COR. Both combinations of FCFS/COR and SIOT/COR produce a significantly higher RMS of tardiness. On the other hand the combinations involving STR priority rule, those are, STR/COR and STR/DOR, result in significantly lower RMS of tardiness compared with other combinations.

Referring to Table VII.5, ANOVA test for RMS tardiness, all the interactions involving factor B, priority rule, are significant interactions. Thus, selection of a due date assignment method, or process batch method, or operator reassignment should be influenced by the method in which priority rules are chosen. Further, from discussions concerning the interactions involving factor B, priority rule, in the previous section, show that any combination involving STR, slack time remaining, produces a significanlty lower RMS of tardiness than other combinations. Thus, the performance of the STR rule should not be influenced by the selection of a due date assignment method, process batch method, and operator reassignment policy.

E.2.1.4 CD Interaction

A plot of the first order interaction between factor C, process batch method, and factor D, operator reassignment policy is presented in Fig. E.4. This plotting is based on means of CD interaction in Table E.8. For DOR operator reassignment policy there is no significant difference in performance amongst any of the process batch methods. This is shown by Fig. E.4 and proved by the comparison test result of means of CD interaction in Table E.9. Although there is no significant difference between combinations of DOR and any of the process batch methods, the combination of DOR/VPB produces a lower RMS of tardiness. In addition, the combination FPB/COR performs significantly worse than the other combinations.

E.2.1.5 ABC Interaction

The second order interaction between factor A (due date assignment method), factor B (priority rule) and factor C (process batch method) proved to be significant according to the result of the comparison test of means of ABC interaction in Table E.11. This significancy is also illustrated in Fig. E.5 and Fig. E.6. Both these figures are based on the data in Table E.10. Fig. E.5 plots the BC interaction for

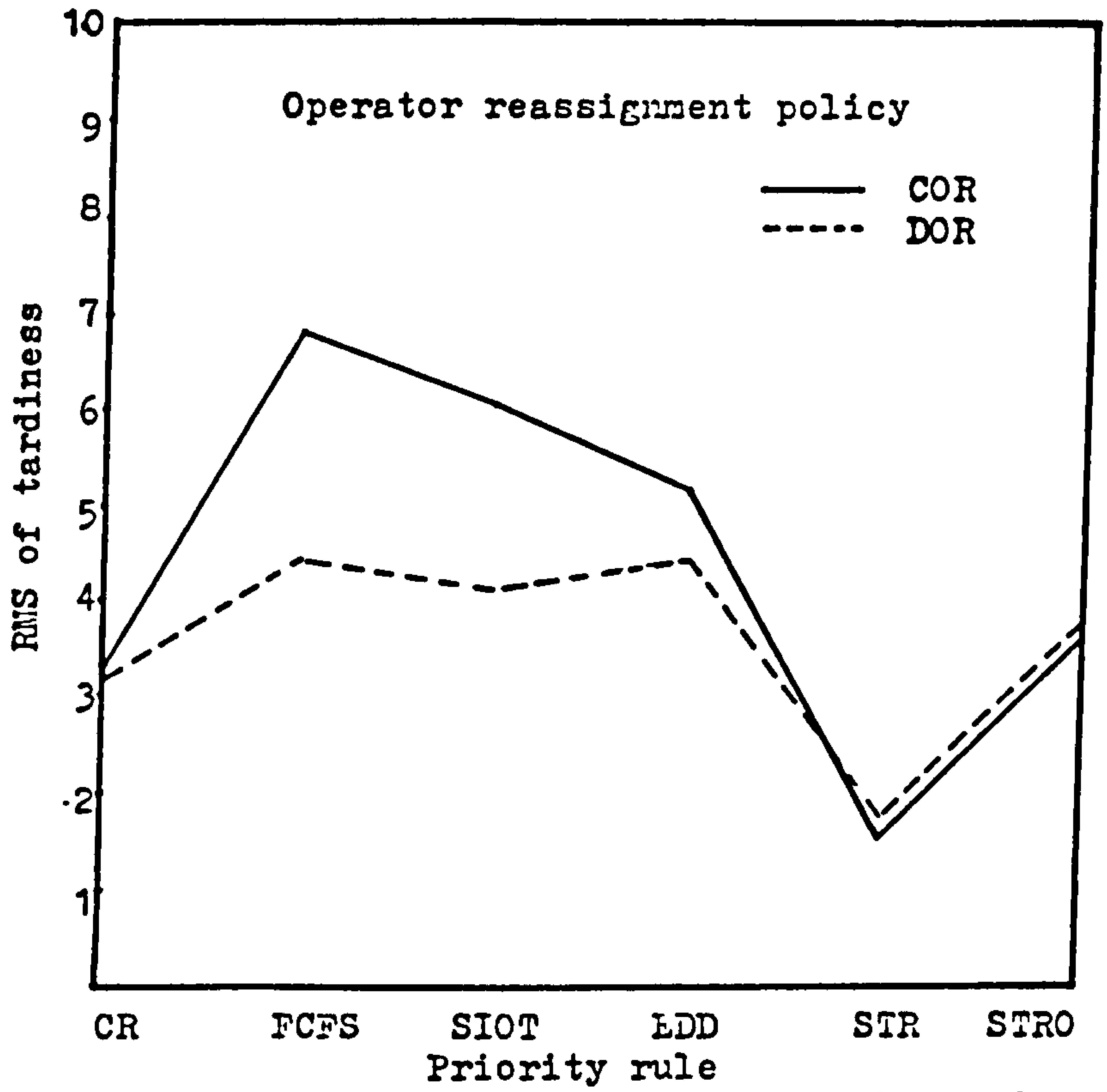


Fig.E.3. Interaction of factor B, priority rule, and factor D, operator reassignment policy in terms of RMS of tardiness.

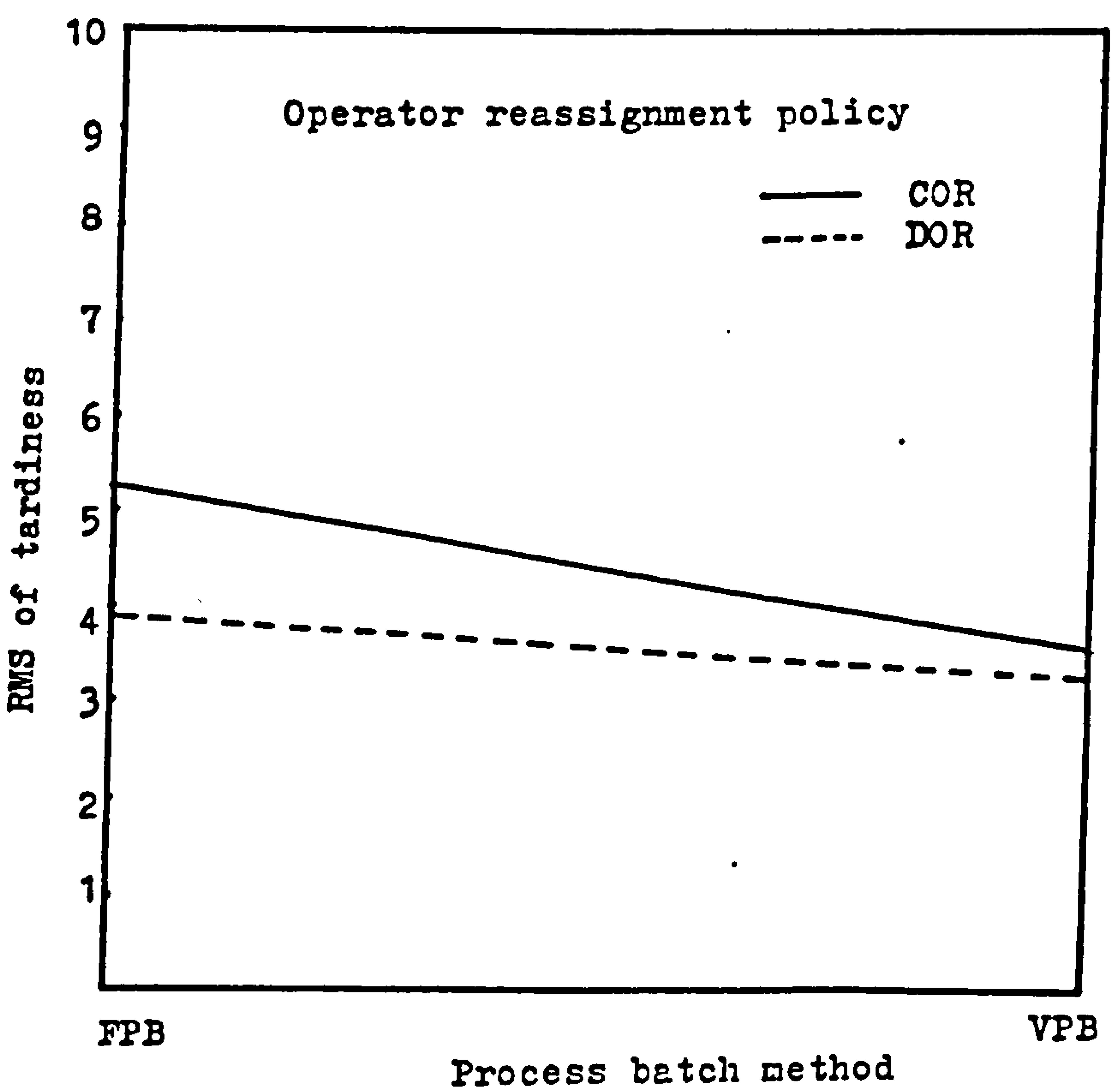
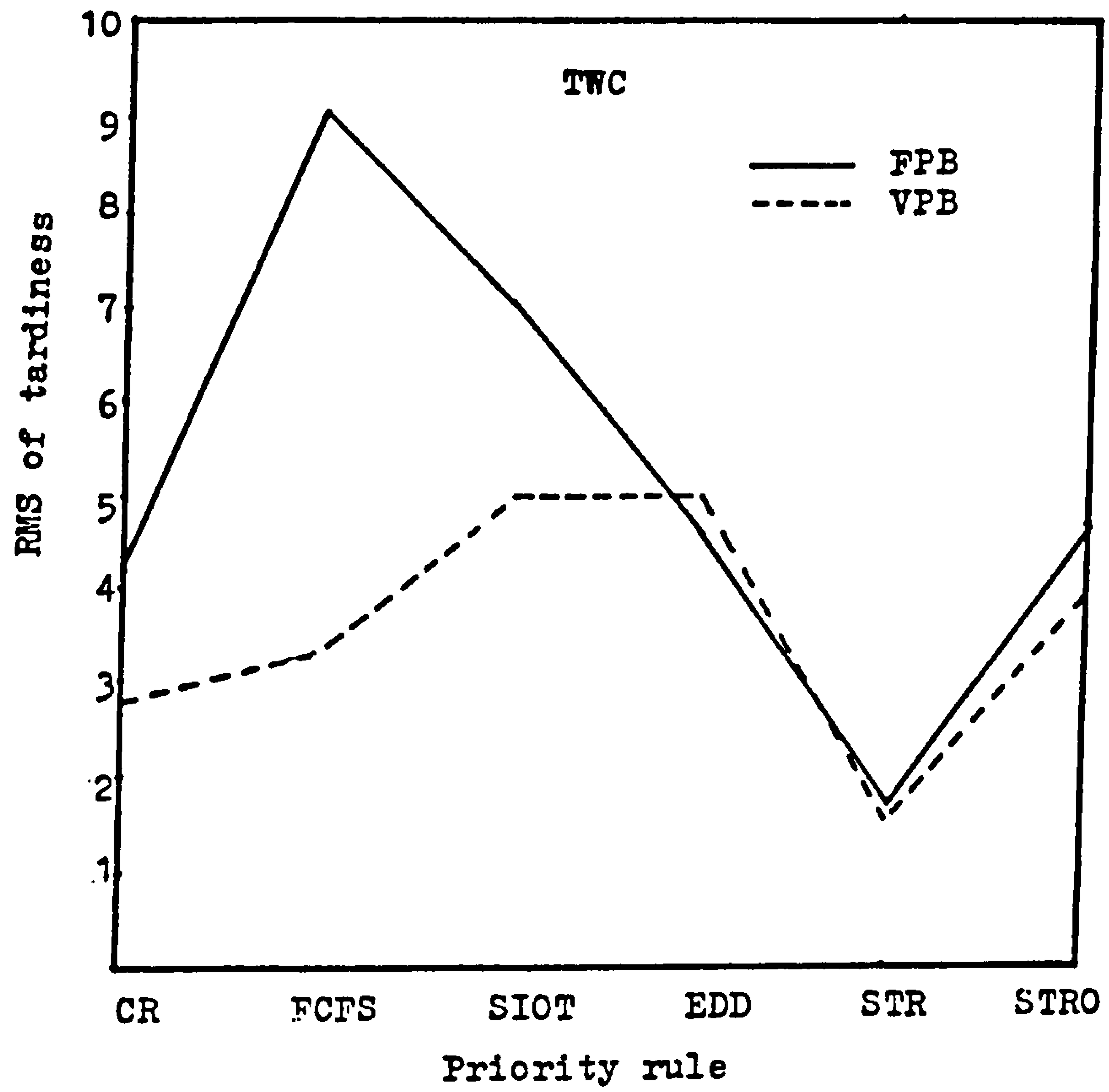


Fig.E.4. Interaction of factor C, process batch method, and factor D, operator reassignment policy in terms of RMS of tardiness



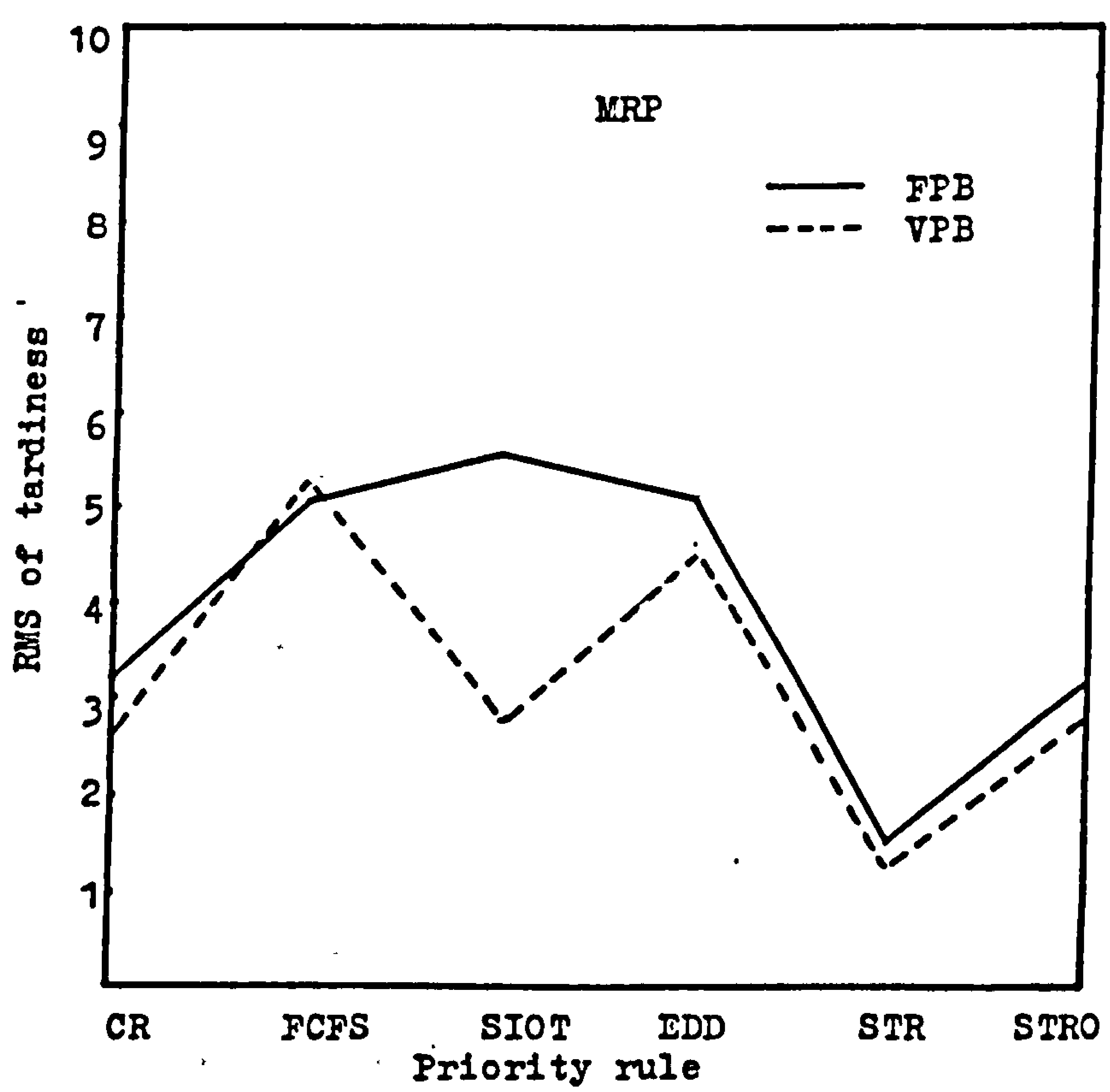


Fig.E.5. BC interaction for each level of factor A in terms of RMS of tardiness.

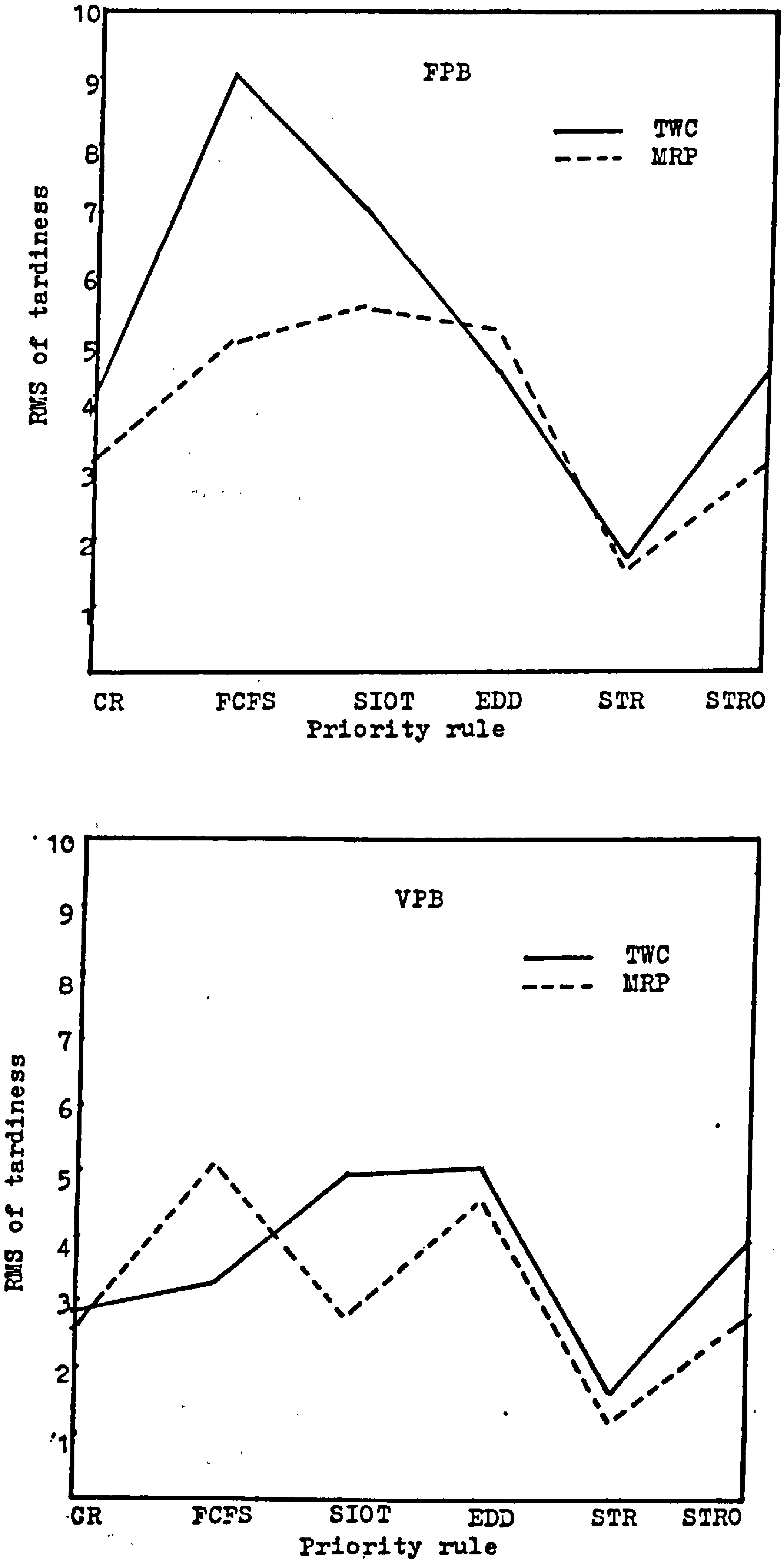


Fig.E.6. AB interaction for each level of factor C in terms of RMS of tardiness.

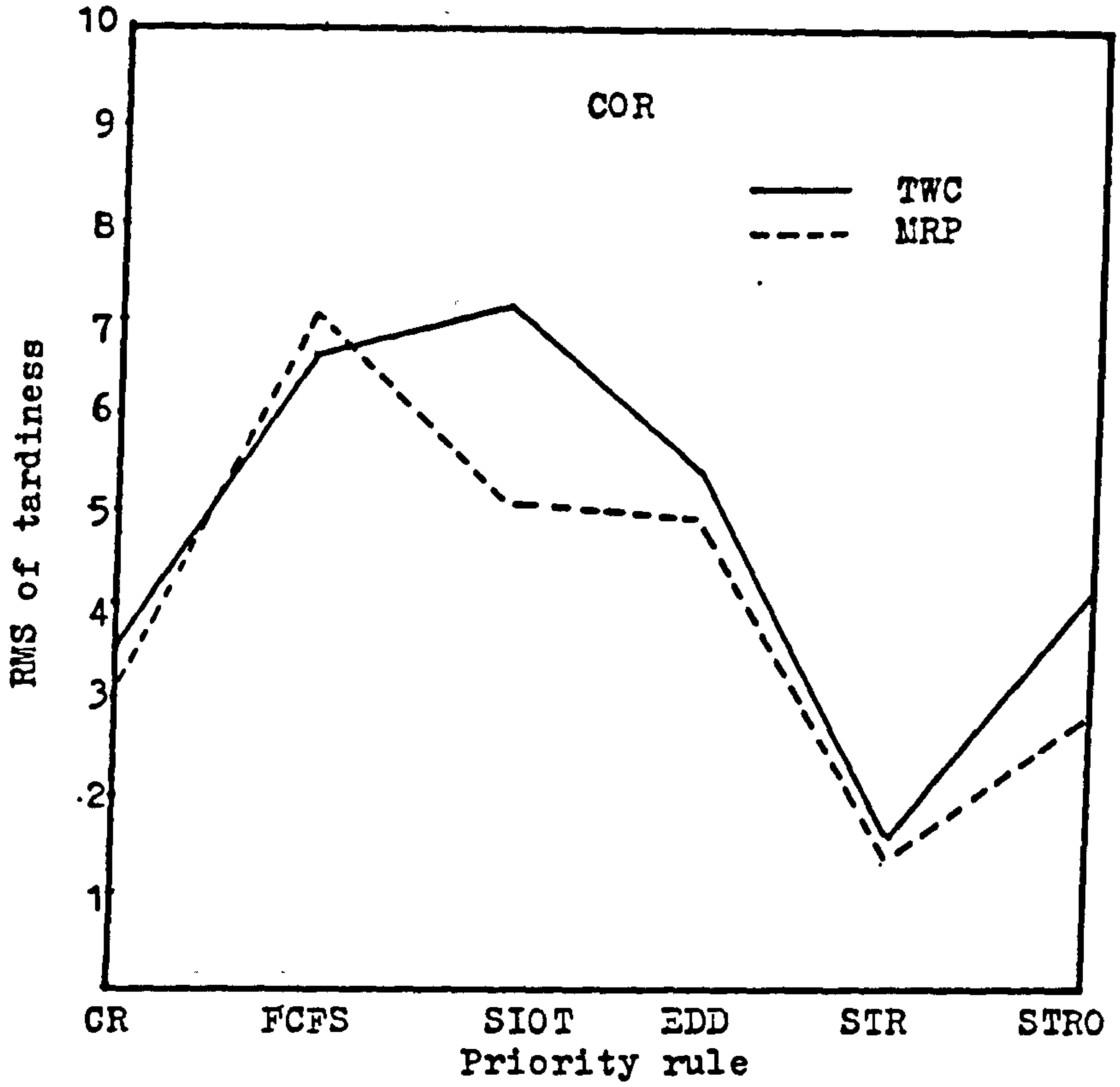
each level of factor A and Fig. E.6 plots the AB interaction for each level of factor C. The analysis of ABC interaction effect provides the following additional information which was not evident from the first order interaction of AB and BC.

a) Every combination (policy) involving the STR priority rule produces a significanly lower RMS of tardiness, thus these combinations are the best performers compared with the other combinations.

b) The combinations consisting of TWC/FCFS/FPB and of TWC/SIOT/FPB produced a significantly higher RMS of tardiness and there is no significant difference between both these combinations. Therefore from all the policies with respect to this interaction, the TWC/FCFS/FPB and the TWC/SIOT/FPB combinations are the worst performers compared with the other combinations.

E.2.1.6 ABD Interaction

Figures E.7 and E.8 illustrate the second order interaction between factor A (due date assignment method), factor B (prioriy rule), and factor D (operator reassignment policy). These figures are based on the values of means of ABD interactions in Table E.12. Fig. E.7 plots the AB interaction for each level factor D, while Fig. E.8 plots the BD interaction for each level factor A. From the illustrations and the comparison test result for the means of ABD interaction in Table E.13 there is more useful information concerning with the operating policy in production scheduling which was not found from the first order interactions of AB and BD. The information is,



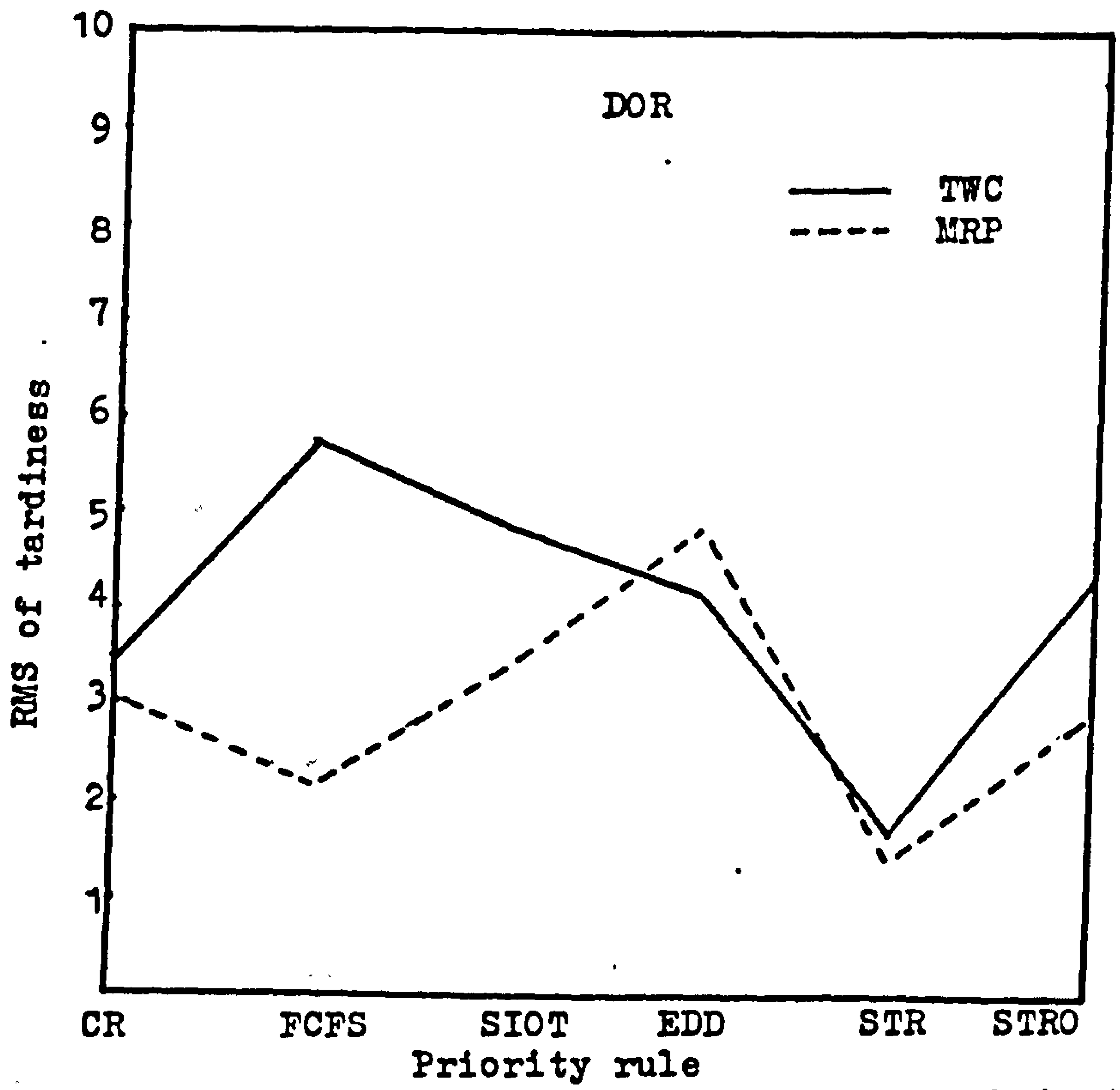
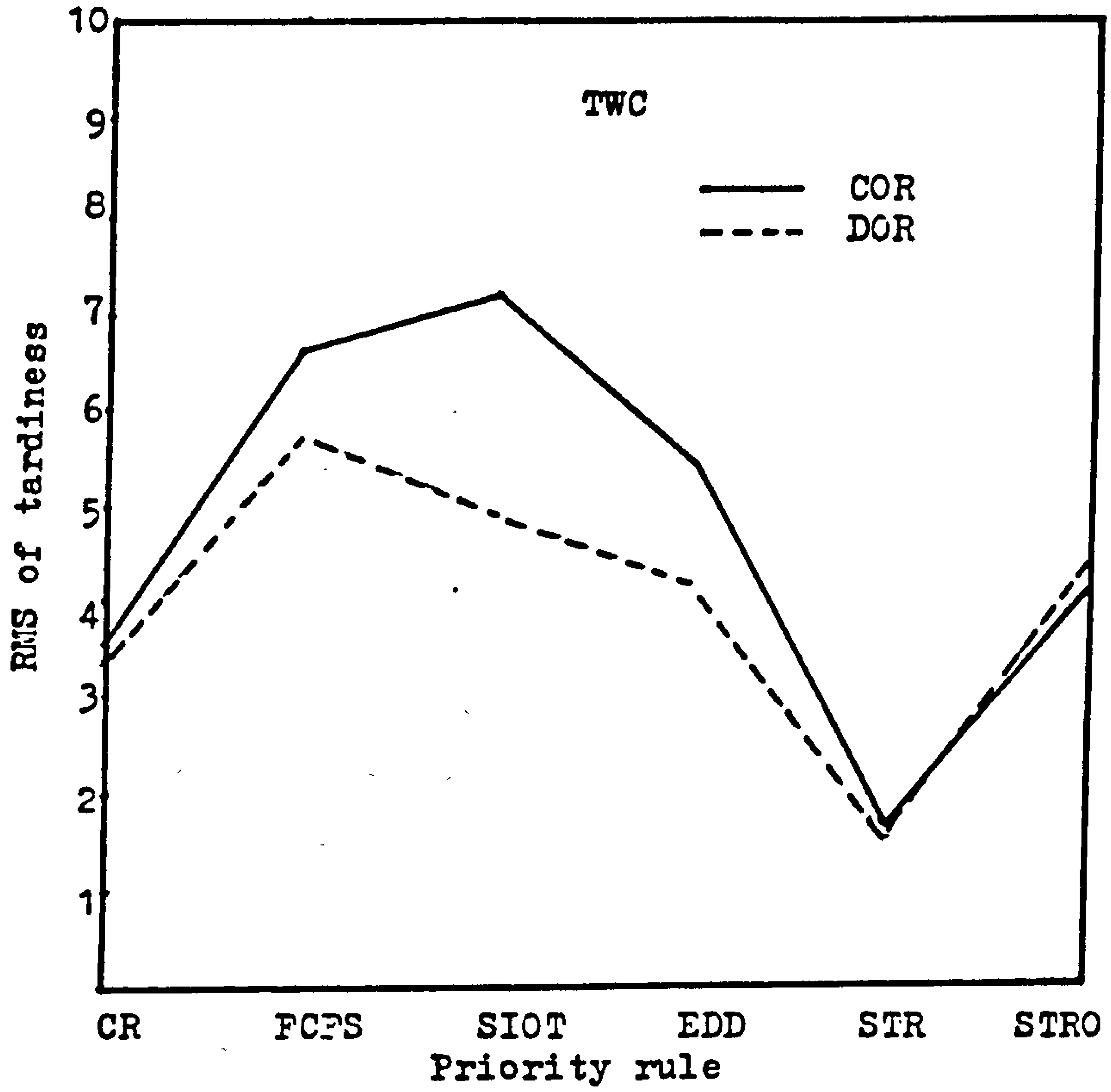


Fig.E.7. AB interaction for each level of factor D in terms of RMS tardiness.



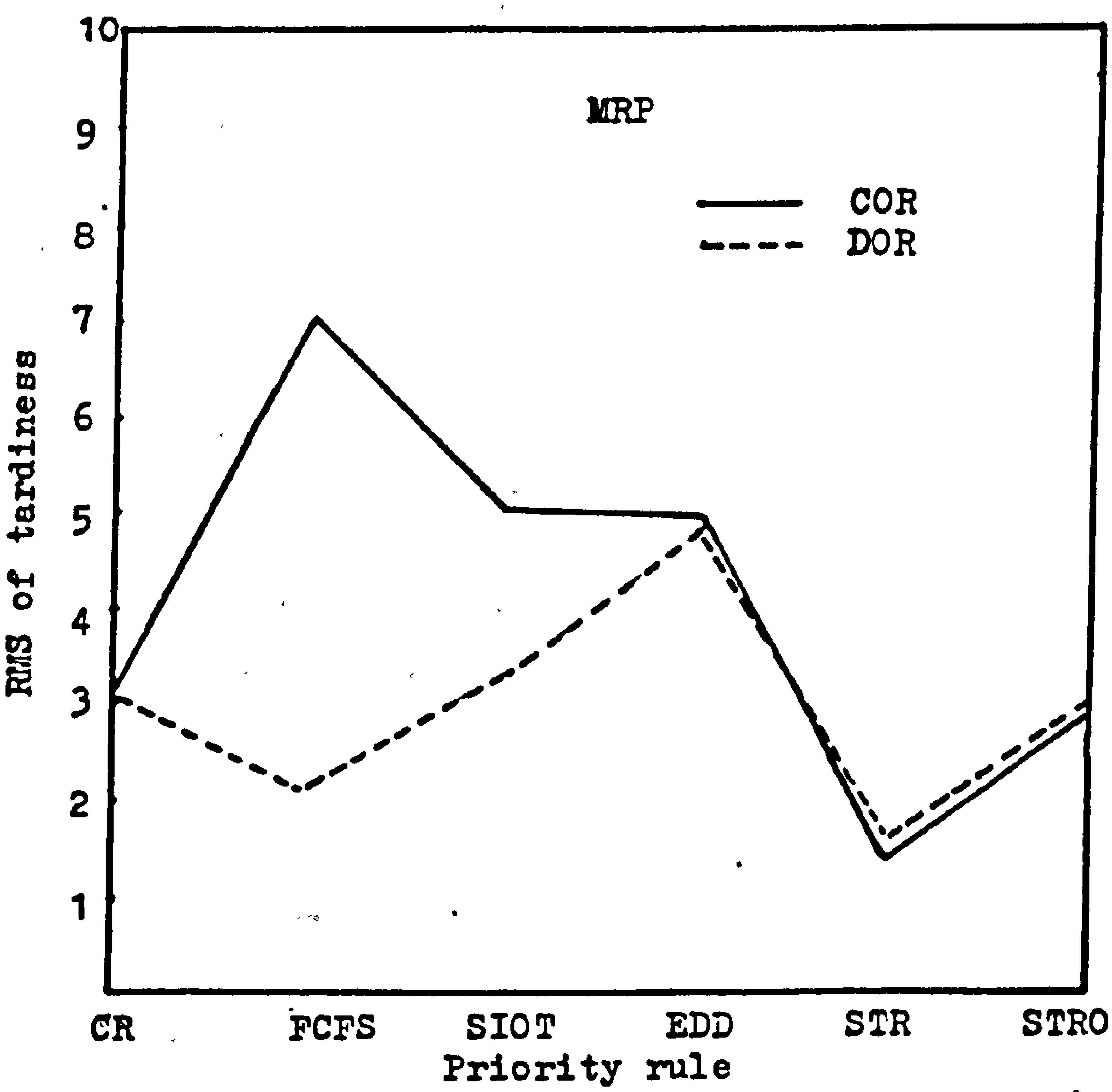


Fig.E.8. BD interaction for each level of factor A in terms of RMS of tardiness.

a) There is a significant difference in RMS of tardiness between combinations involving the STR priority rule with the other combinations except with the MRP/CR/DOR combination. Further, the combinations involving the STR priority rule and the MRP/CR/DOR produce a significantly lower RMS of tardiness compared with the other combinations.

b) There is no significant difference between combinations TWC/FCFS/COR, MRP/FCFS/COR, and TWC/SIOT/COR and the three combinations produce a significantly higher RMS of tardiness compared with the other combinations.

E.2.1.7 BCD Interaction

Fig. E.9 and Fig. E.10 depicted the second order interaction between factor B (priority rule), factor C (process batch method), and factor D (operator reassignment policy) were based on the values of means of BCD in Table E.14. Fig. E.9 illustrates the BC interaction for each level of factor D and Fig. E.10 illustrates the BD interaction for each level of factor C. From Fig. 9-10 and the comparison test result of means of BCD interaction in Table E.15, it can be concluded that,

a) There is a significant difference in the RMS of tardiness between combinations involving the STR priority rule with the other combinations except with the combinations of CR/VPB with any of the operator reassignment policies. Furthermore, every combination involving the STR priority rule and the combinations CR/VPB with any of the operator reassignment policies performs significantly better, rather than the other combinations.

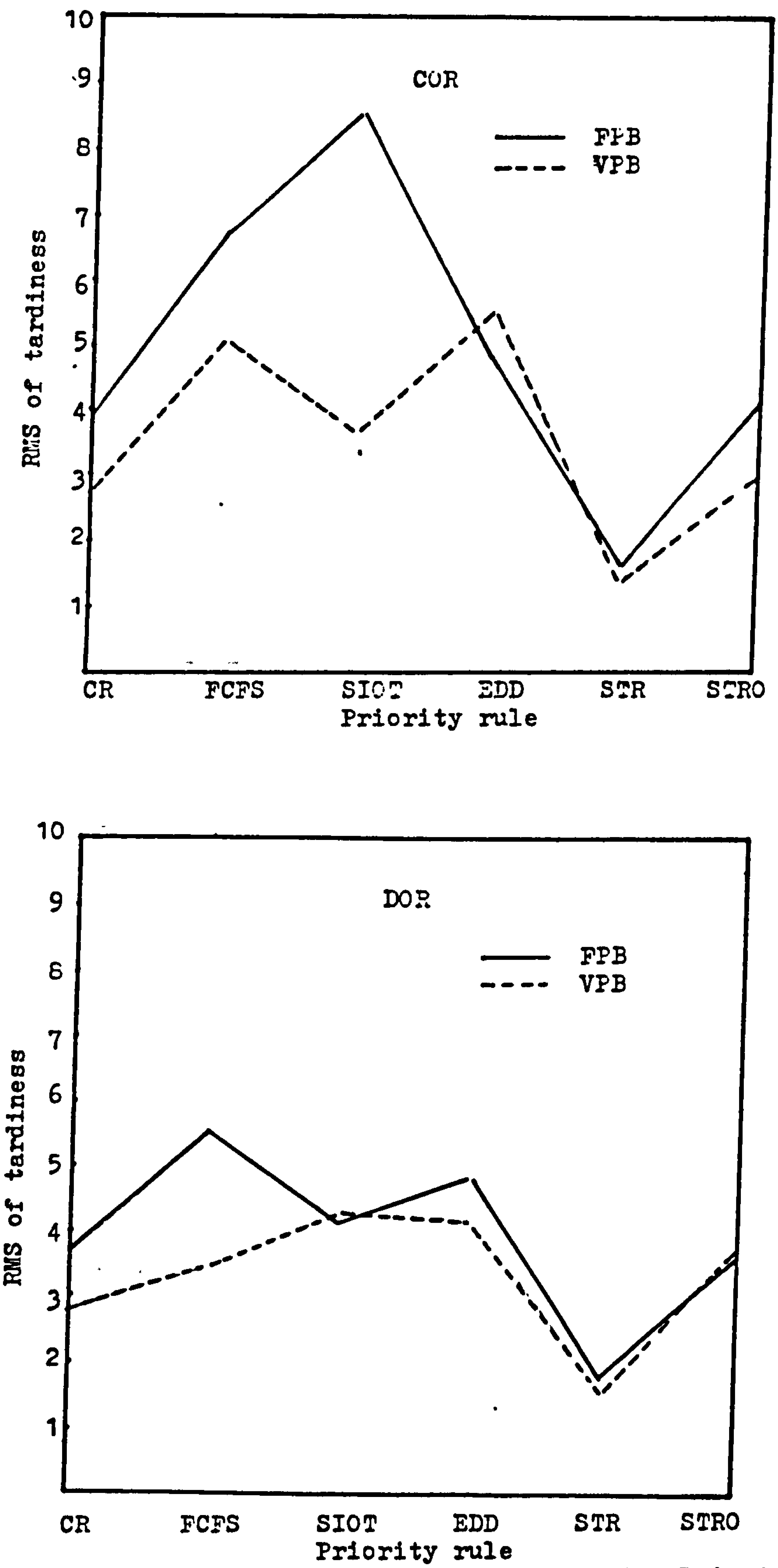


Fig.E.9. BC interaction for each level of factor D in terms of RMS of tardiness.

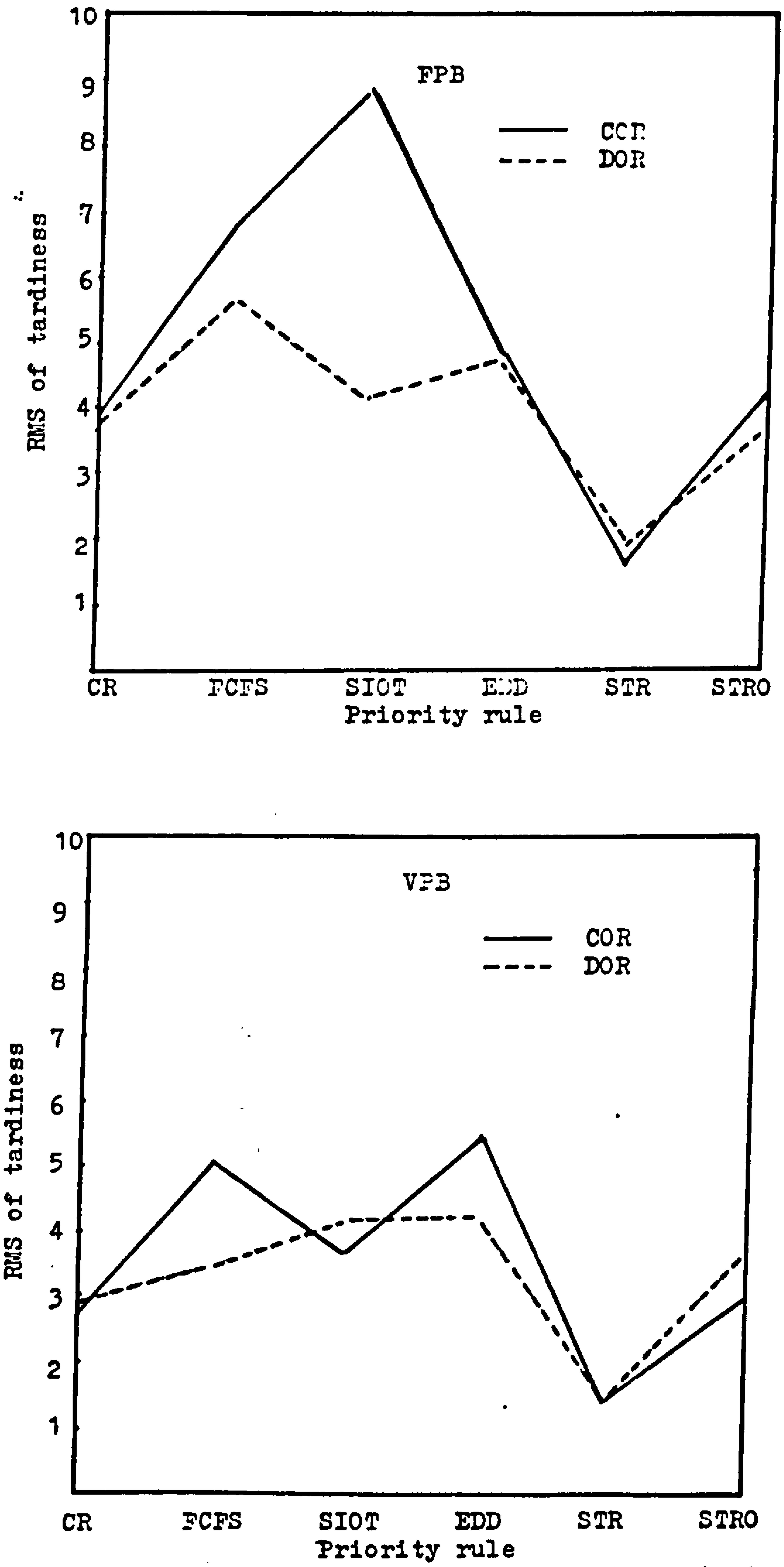


Fig.E.10. BD interaction for each level of factor C in terms of RMS of tardiness

b) The combination of SIOT/FPB/COR produces a significantly higher RMS of tardiness compared with the other combinations.

E.2.2 Means of work in progress

E.2.2.1 AB Interaction

Fig. E.11 based on the means of AB interaction in Table E.16 plots the first order interaction between factor A, due date assignment method, and factor B, priority rule in terms of mean work in progress performance. From Fig. E.11 and the significance test of means of AB interaction in Table E.17, it can be proved that all combinations involving factors A and B are not significantly different in terms of work in progress except for the combinations including TWC/EDD, TWC/STR and TWC/SIOT. Further, those three combinations produce a significantly higher WIP than other combinations and there is not significant difference between them.

E.2.2.2 AC Interaction

Fig. E.12 based on the means of AC interaction, Table E.18 illustrates the interaction of factor A, due date assignment method, and factor C, process batch method. Fig. E.12 and the significance test of AC interaction in Table E.19 prove that every combination of VPB process batch method and ude date assignment method performs significantly better than every combination of FPB process batch method and due date assignment method. The worst result is obtained when FPB is combined with TWC. In addition, the VPB process batch method is the best of the process batch methods tested, and is not significantly affected by

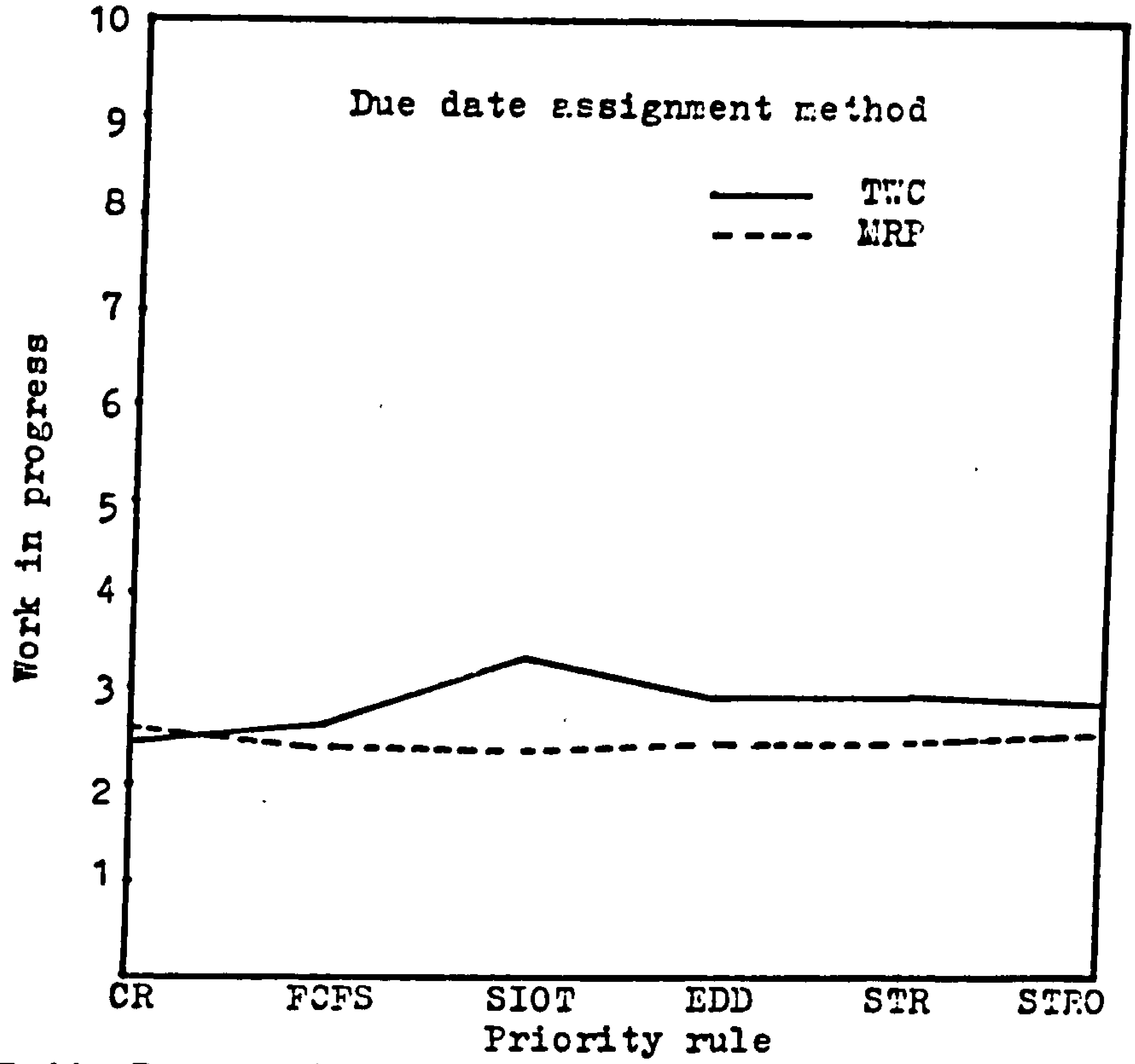


Fig.E.11. Interaction of factor A, due date assignment method, and factor B, priority rule in terms of work in progress.

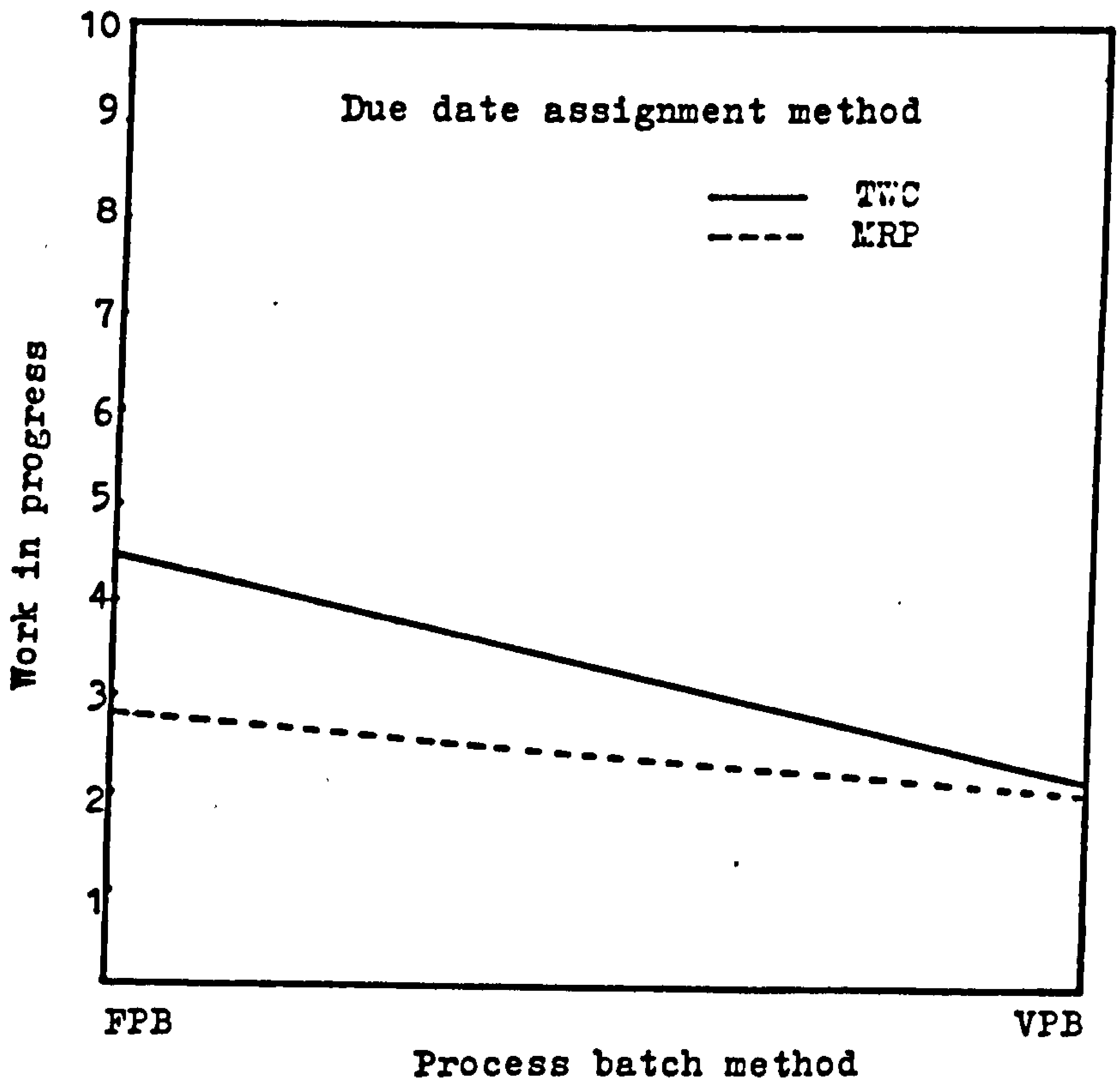


Fig.E.12. Interaction of factor A, due date assignment method, and factor C, process batch method in terms of work in progress.

a combination with any of due date assignment methods.

E.2.2.3 AD Interaction

A plot of the first order interaction between factor A, due date assignment method, and factor D, operator reassignment policy, is shown in Fig. E.13. Fig. E.13 is based on the means of AD interaction in Table E.20. Both Fig. E.13 and the significancy test in Table E.21 show that the combinations involving MRP, due date assignment method, with any of the operator reassignment policy do not differ significantly in terms of work in progress performance and produce a lower work in progress compared with the other combinations. Meanwhile, the TWC/COR produces a significantly higher work in progress.

E.2.2.4 BC Interaction

The first order interaction between factor B, priority rule, and factor C, process batch method in terms of work in progress, is illustrated in Fig. E.14. This figure is based on the data in Table E.22. From Fig. E.14 and the significance test results in Table E.23 it can be concluded that the SIOT/VPB combination performs significantly better than the other combinations. Furthermore, the combinations which include FCFS/FPB and SIOT/FPB do not differ significantly and produce higher work in progress compared with the other combinations.

E.2.2.5 BD Interaction

Fig. E.15 based on the data in Table E.24 represents the first order interaction between factor B,

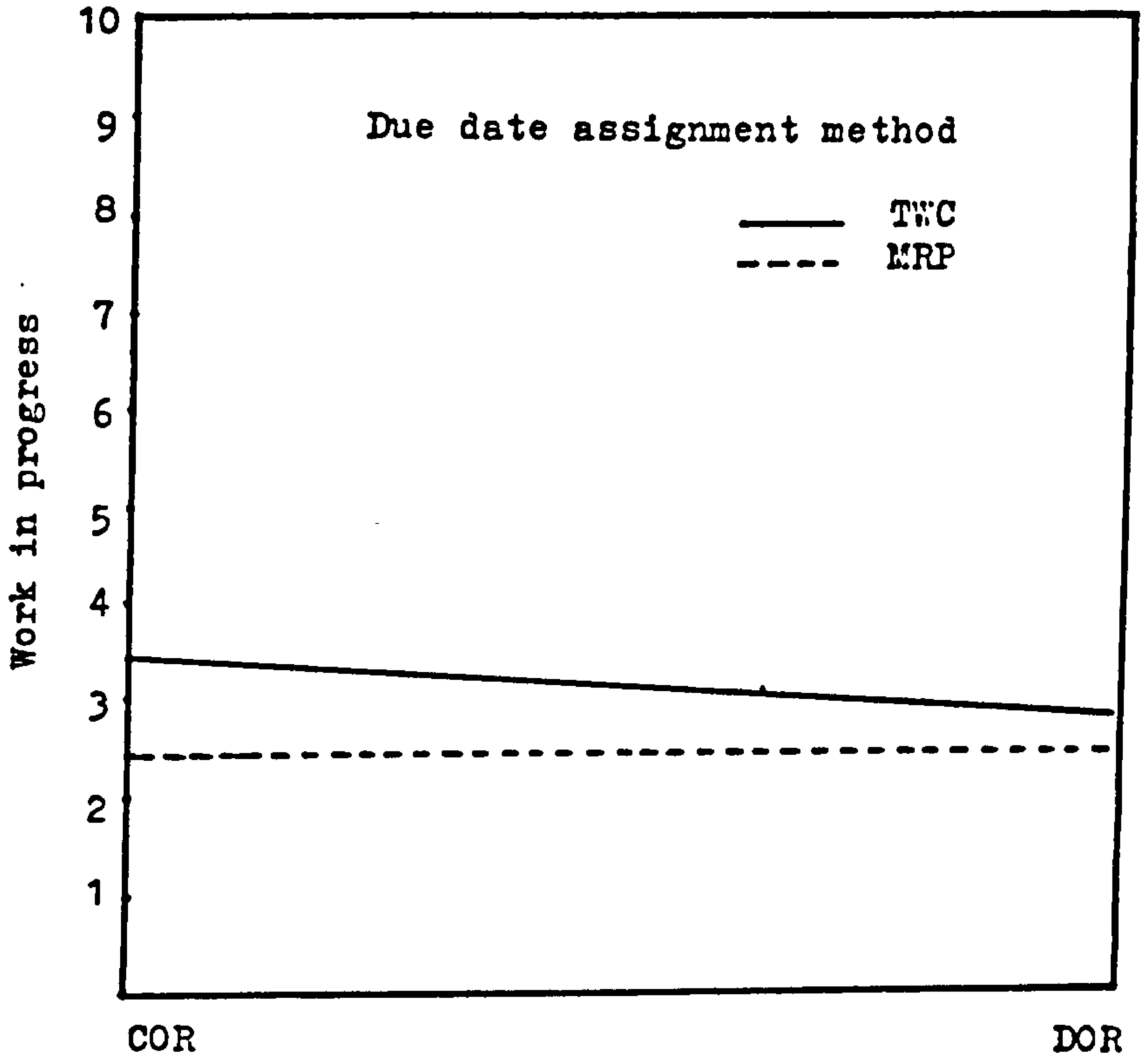


Fig.E.13. Interaction of factor A, due date assignment method, and factor D, operator reassignment policy in terms of work in progress

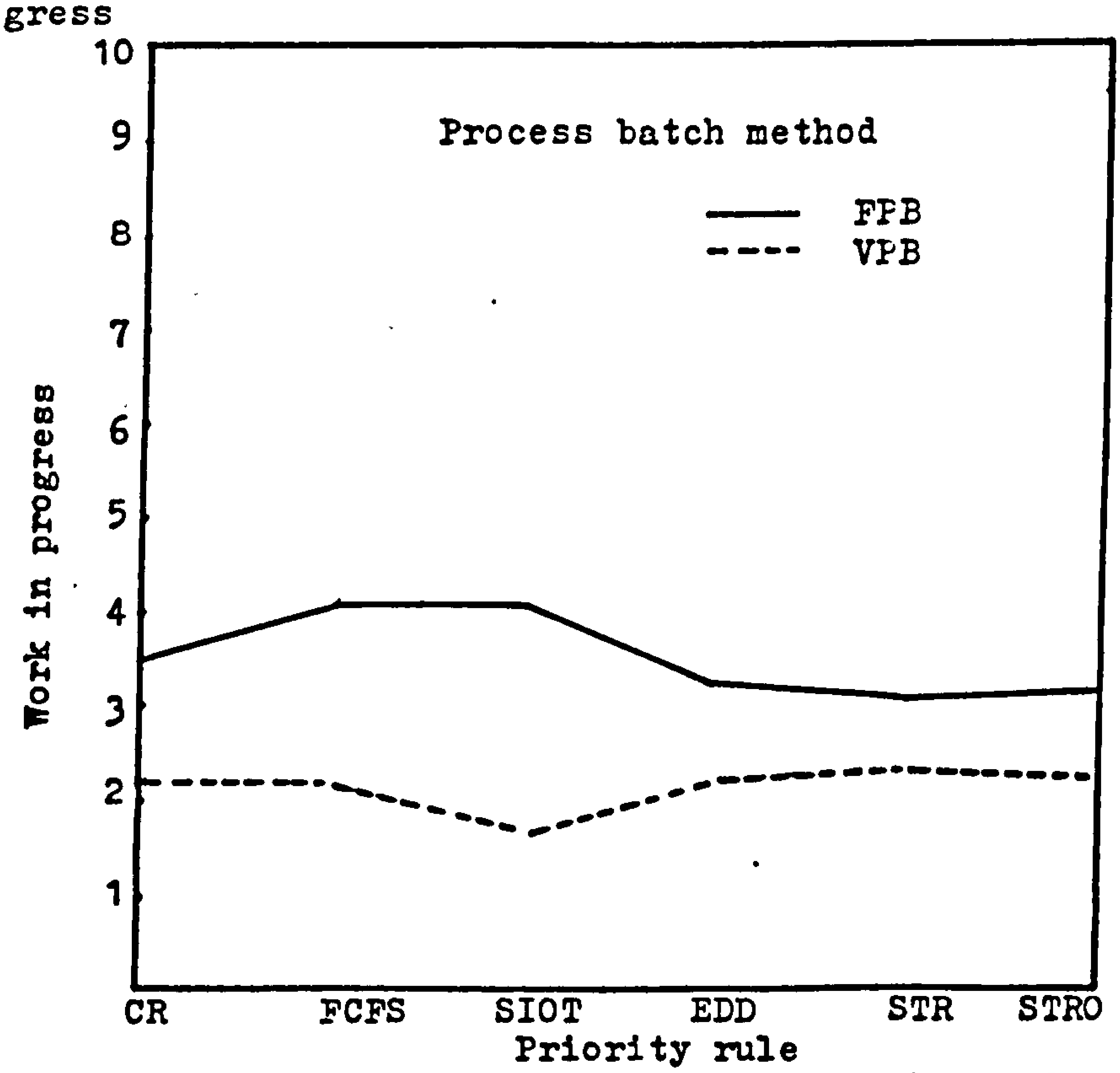


Fig.E.14. Interaction of factor B, priority rule, and factor C, process batch method in terms of work in progress

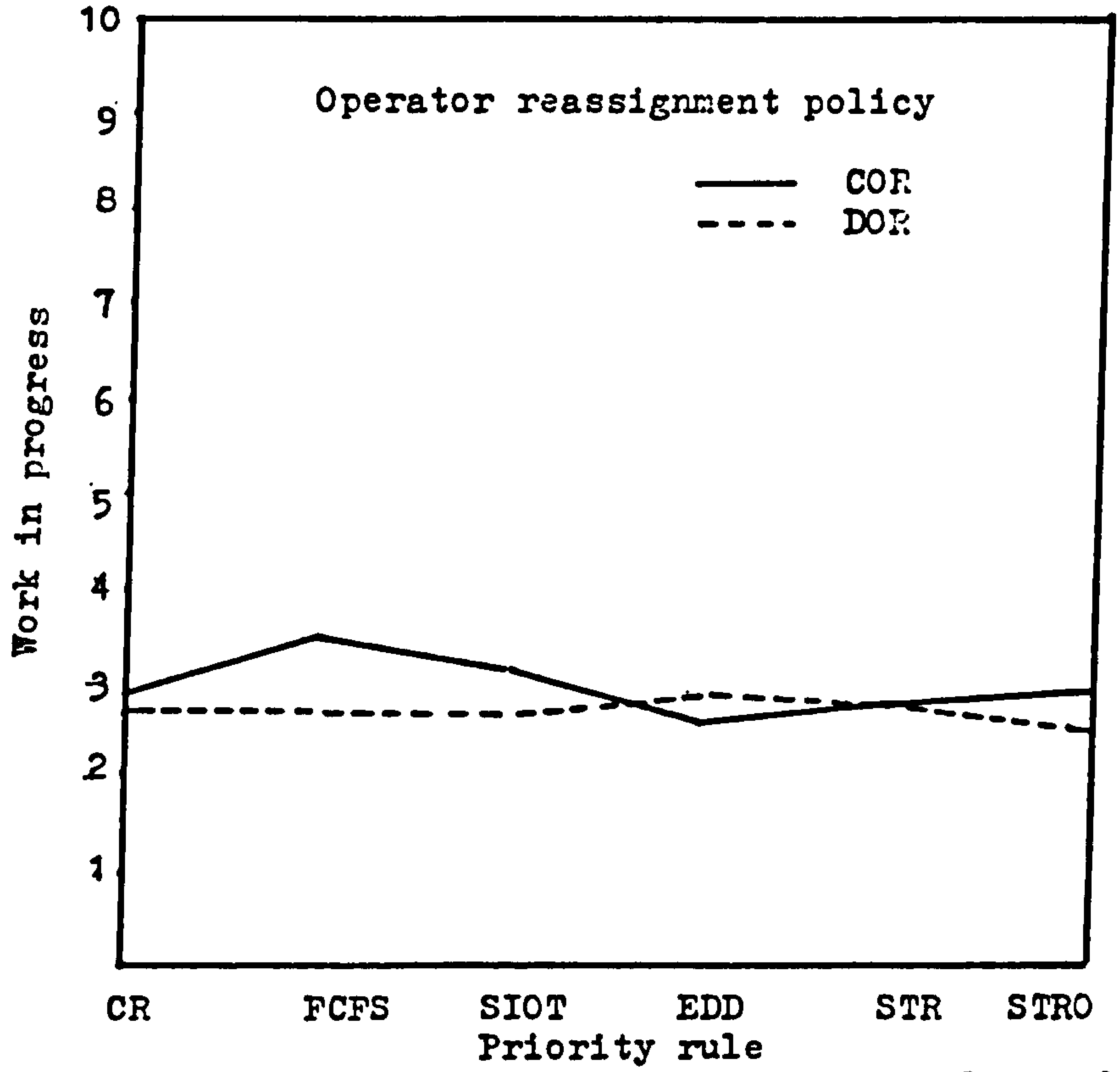


Fig.E.15. Interaction of factor B, priority rule, and factor D, operator reassignment policy in terms of work in progress.

priority rule, and factor D, operator reassignment policy. From Fig. E.15, it can be shown that there is no difference in work in progress performance between the combinations which involve factors B and D except with the FCFS/COR. This evidence is also substantiated by the significancy test of means of BD interaction in Table E.25. Further, the test proves that the FCFS/COR produces significantly a higher work in progress compared with the other combinations. Therefore, the FCFS/COR is the worst performer in terms of work in progress performance from all combinations involving factors B and D.

The ANOVA test for work in progress performance in Table VII.6 shows that all the interactions involving factor A, due date assignment method, are significant interactions. Thus, the selection of a priority rule, or process batch method, or operator reassignment policy would be influenced by the method by which due dates of finished products are assigned. Further, Table VII.6 also shows that all the interactions involvong factor B, priority rule, are the significant interactions in terms of work in progress performance. Therefore, the selection of a due date assignment method, or process batch method, or operator reassignment policy may be influenced by the method by which priority rules are chosen with respect to work in progress performance criterion. From discussions concerning the first order interactions in terms of work in progress performance can be drawn the conlusions:

a) Every combination involving VPB, variable process batch method produces a lower work in progress compared with combinations involving FPB, fixed process batch method.

b) The combination which consists of SIOT/VPB produces the lowest work in progress compared with the other combinations.

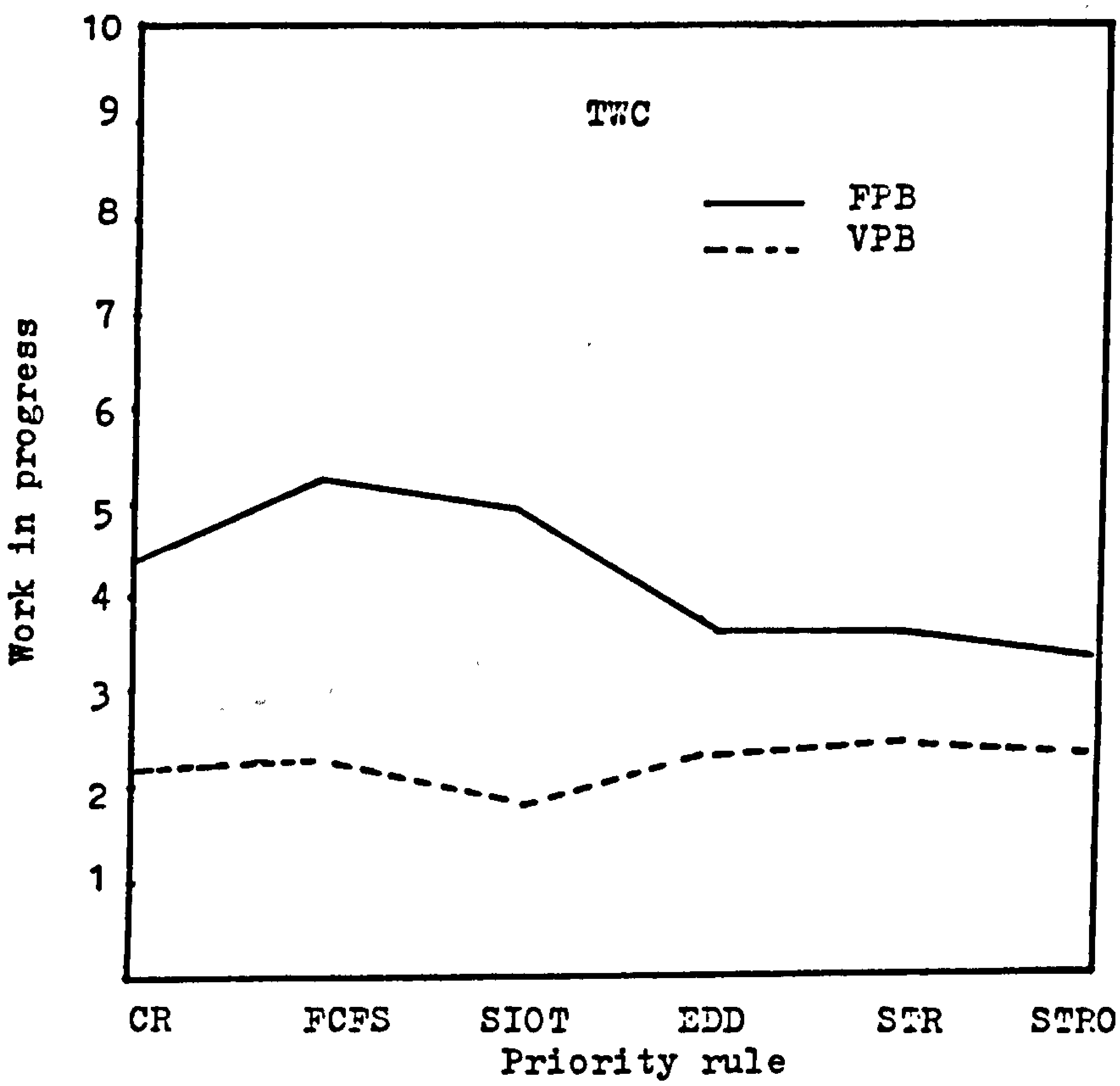
E.2.2.6 ABC Interaction

The second order interaction between factor A (due date assignment method), factor B (priority rule) and factor C (process batch method) proved to be significant according to the comparison test of means of ABC interaction in Table E.27. Fig. E.16 and Fig. E.17, based on the means of ABC interactions in Table E.26, also illustrate the significancy of this interaction. Fig. E.16 illustrates the BC interaction for each level of factor A while Fig. E.17 illustrates the AB interaction for each level of factor C. Through the analysis of ABC interaction on work in progress performance can be drawn conclusions which are not evident from the first order interactions of AB, AC, and BC. These three conclusions are:

a) The combinations which include MRP/SIOT/VPB, TWC/SIOT/VPB, TWC/CR/VPB and MRP/FCFS/VPB do not differ in work in progress performance and produce significantly lower work in progress compared with the other combinations.

b) The combinations which include TWC/SIOT/FPB and TWC/FCFS/FPB perform worst and result in significantly higher work in progress compared with the others.

c) Referring to Table VII.6, the ABC interaction is the only significant interaction of the second order interaction. Thus the selection of the



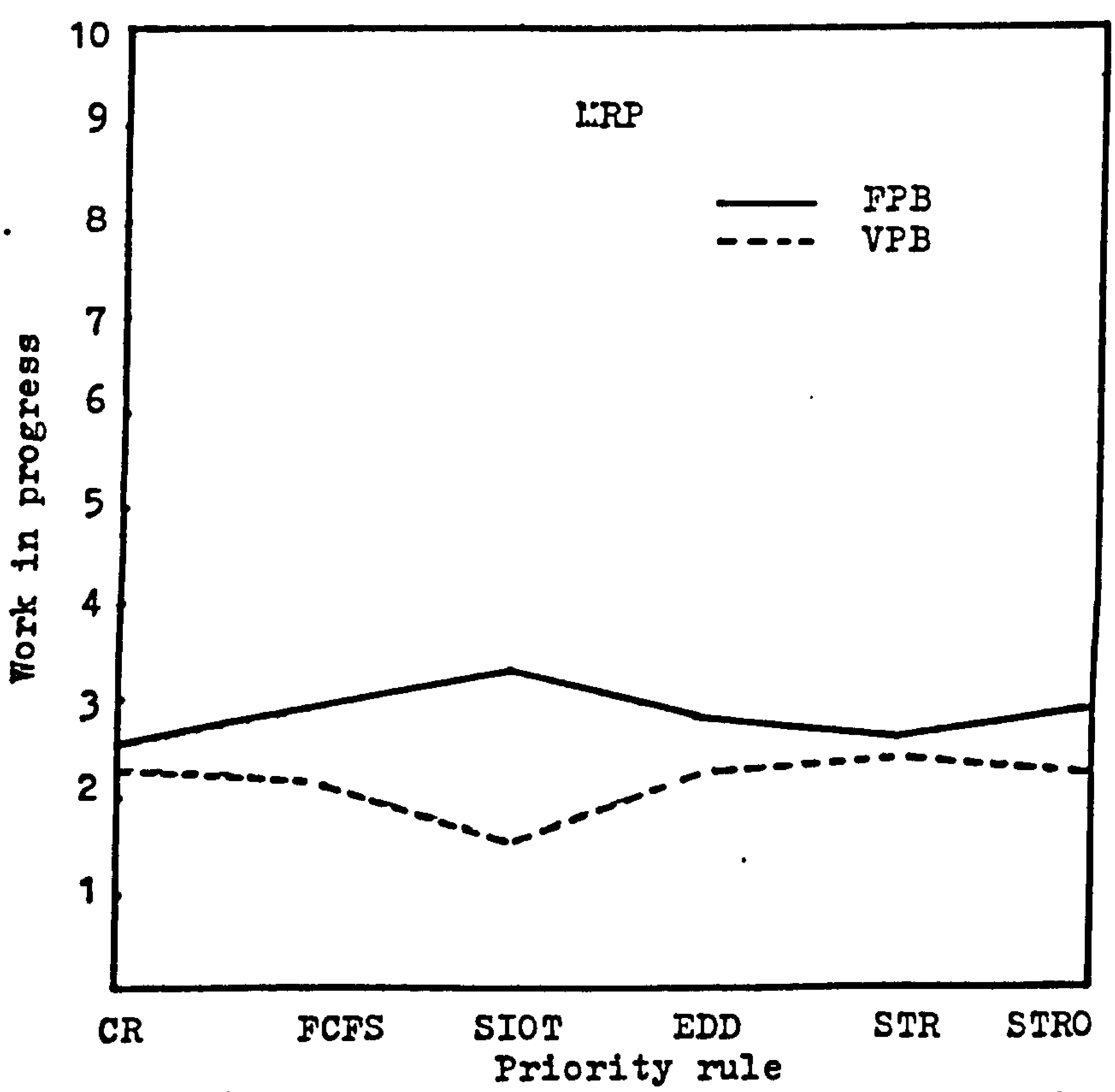
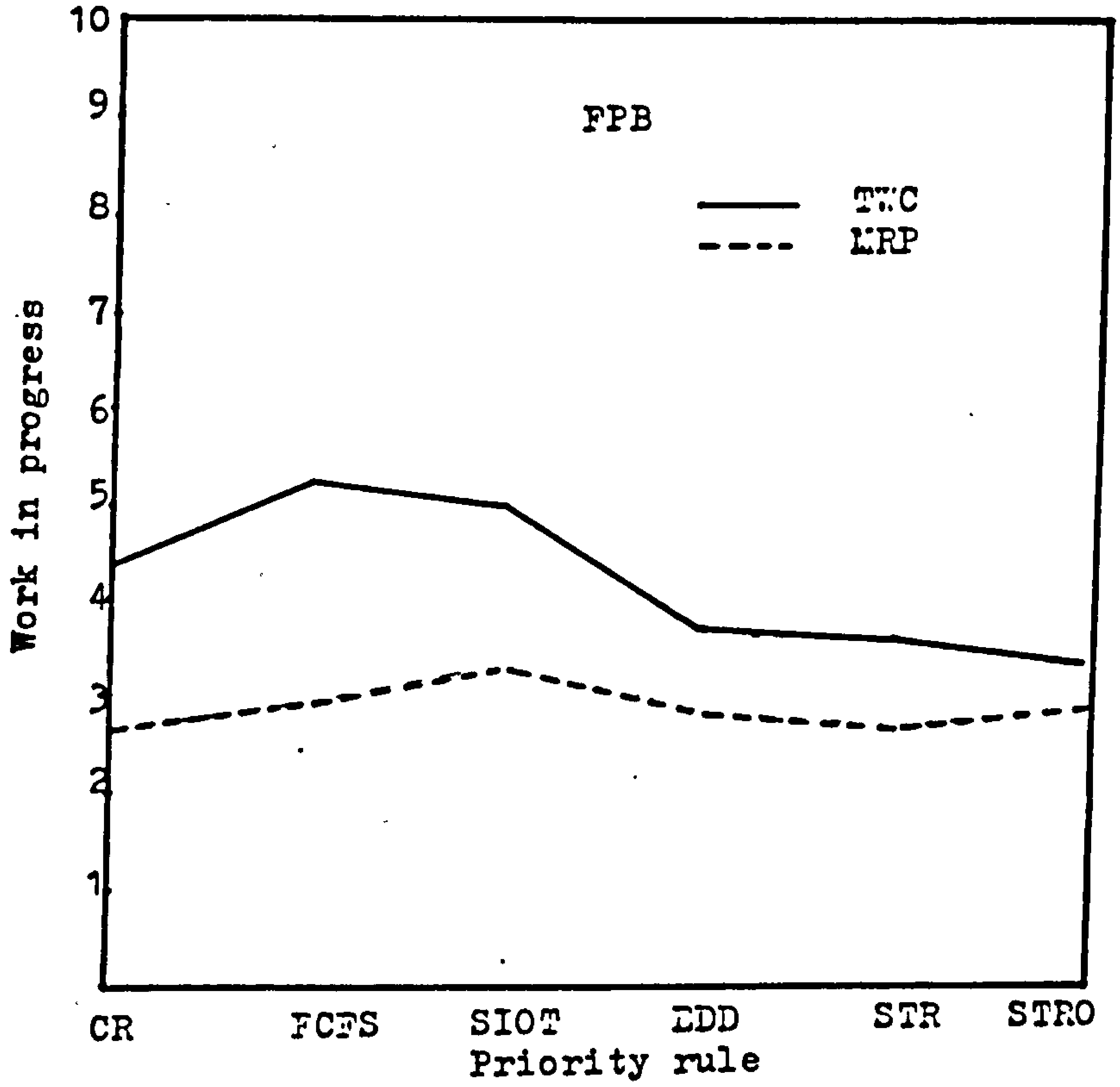


Fig.E.16. BC interaction for each level of factor A in terms of work in progress.



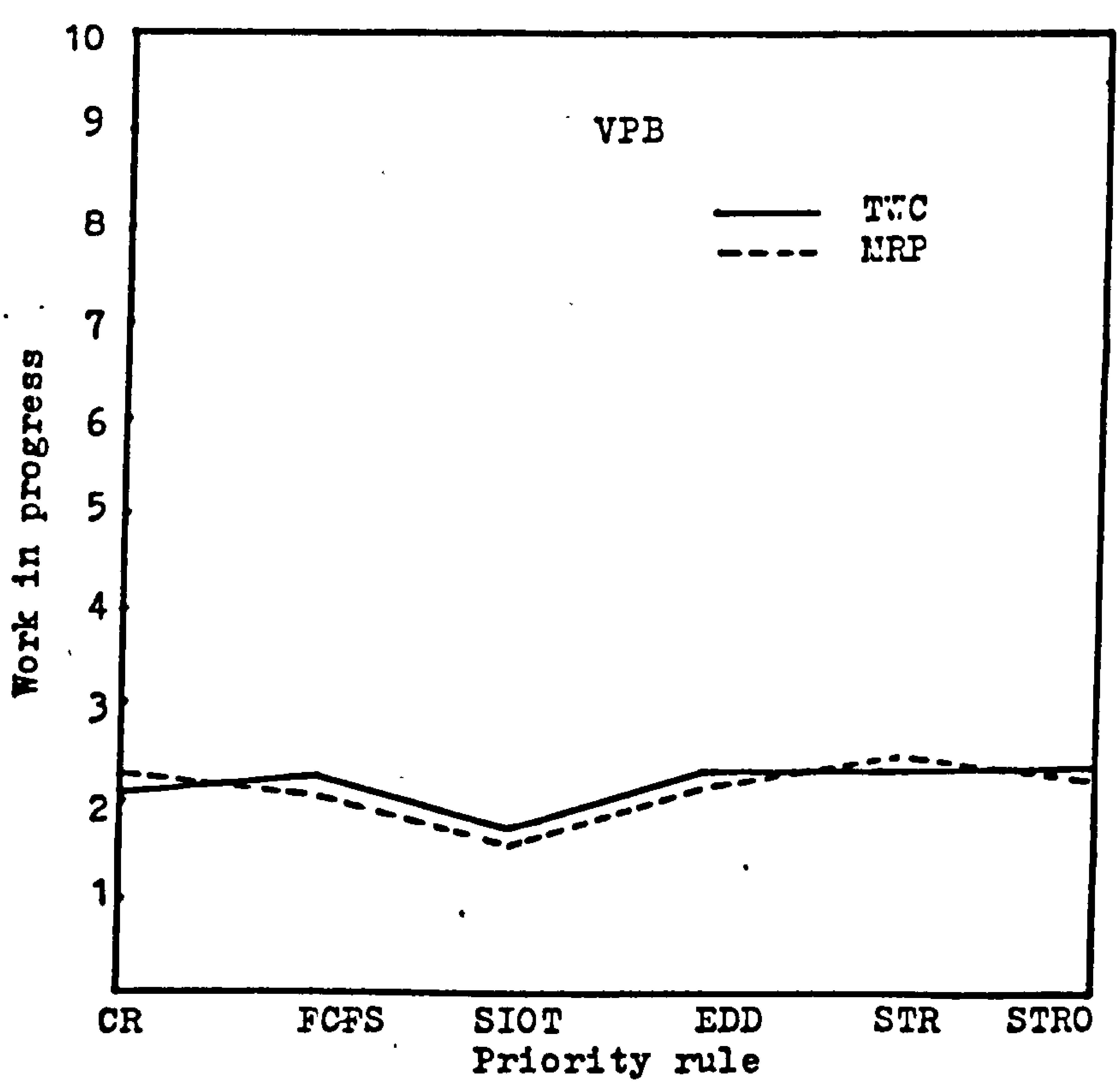


Fig.E.17. AB interaction for each level of factor C in terms of work in progress.

combination of a due date assignment method, a priority rule, and a process batch method might not be influenced by the policy in which operator reassignment is applied. In other words the operator reassignment policy does not have a pronounced effect on work in progress performance.

E.2.3 Means of machine utilisation

E.2.3.1 AB Interaction

Fig. E.18 depicts the first order interaction between factor A, due date assignment method, and factor B, priority rule in terms of machine utilisation performance. Fig. E.18 is obtained by plotting the data of means of AB interaction given in Table E.28. The significance test of the means of AB interation in Table E.29 along with Fig. E.18 pronounces that the combination involving MRP/STR produces a significantly higher machine utilisation. Therefore, these combinations are the best performers in terms of machine utilisation compared with the other combinations. On the other hand, the combinations which include TWC/SIOT, TWC/CR, TWC/FCFS, MRP/STRO, and TWC/EDD, do not differ significantly and produce a lower machine utilisation compared with the other combinations. Thus, these combinations are the worst performers in respect of machine utilisation performance.

E.2.3.2 AC Interaction

Fig. E.19 based on the data of mean AC interaction in TAble E.30 illustrates the first order interaction between factor A, due date asignment method, and factor C, process batch method. Furthermore, Fig.

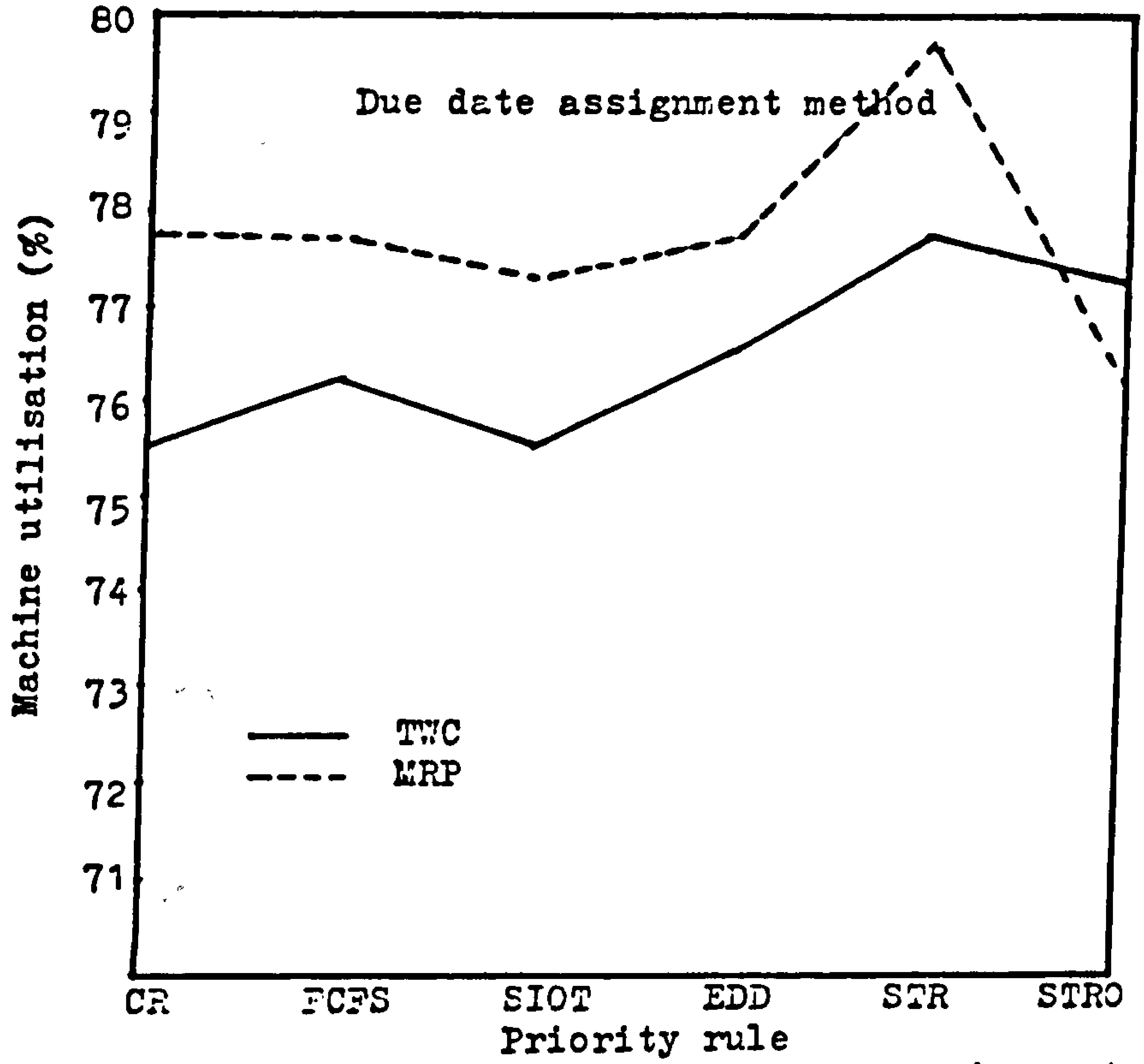


Fig.E.18. Interaction of factor A, due date assignment method, and factor B, priority rule in terms of machine utilisation.

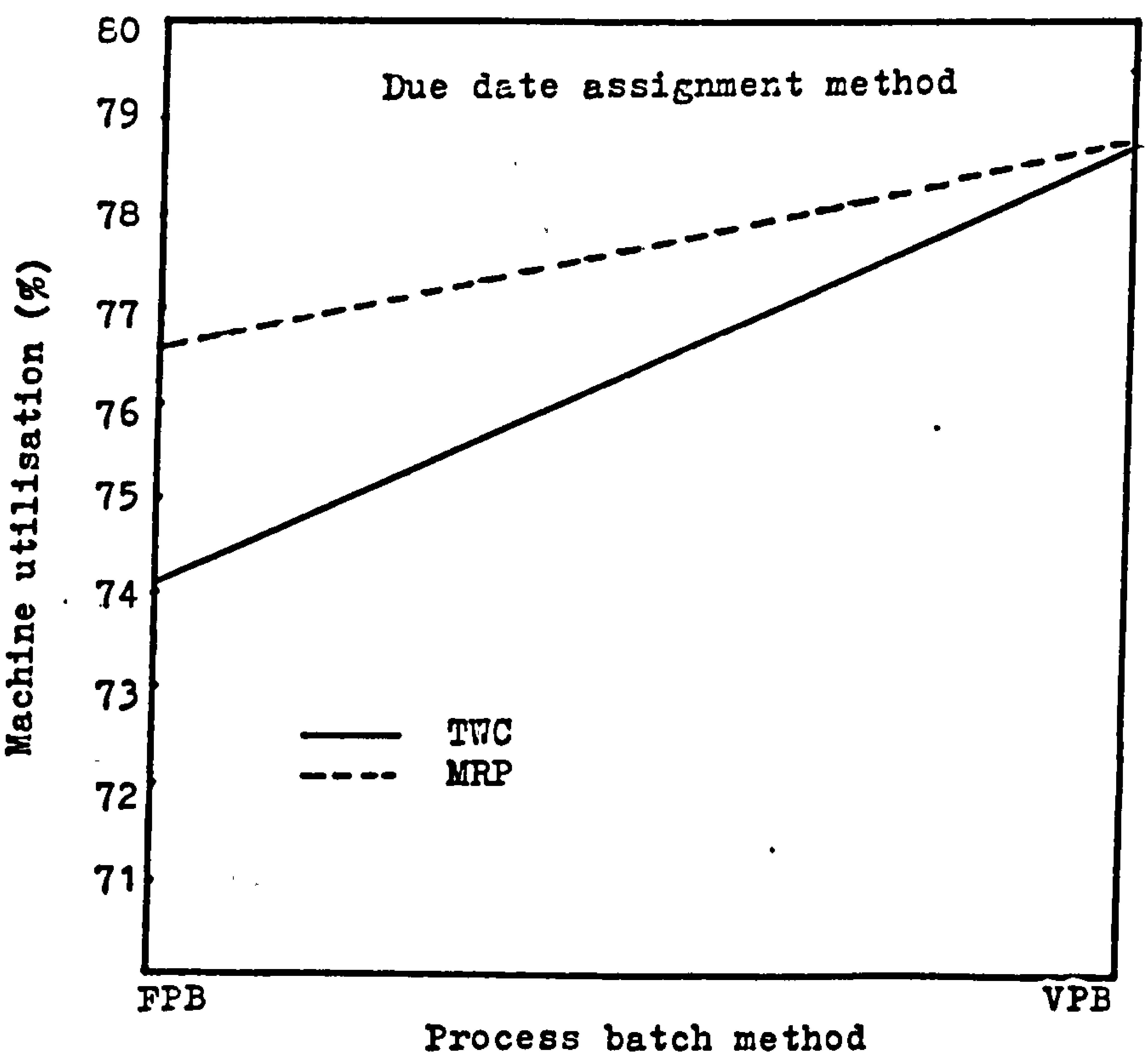


Fig.E.19. Interaction of factor A, due date assignment method, and factor C, process batch method in terms of machine utilisation

E.19 shows that any of the combinations involving VPB, variable process batch method, produces a higher machine utilisation than any of the combinations involving FPB, fixed process batch method. This fact is also substantiated by the significance test result of the means of AC interaction in TAble E.31. Statistically, this test pronounces that every combination of VPB with any of due date assignment methods performs significantly better than every combination of FPB with any of the due date assignment methods.

E.2.3.3 BC Interaction

Plotting the data of means of BC interaction in Table E.32 produces Fig. E.20 which illustrates the first order interaction between factor B, priority rule, and factor C, process batch method. According to the significance test of BC interaction in Table E.33 and as shown in Fig. E.20, it can be proved that every combination of VPB, variable process batch, method with any of the priority rules tested during the simulation provides a higher machine utilisation and performs significantly better than every combination of FPB, fixed process batch, method with any of the priority rules.

E.2.3.4 CD Interaction

Fig. E.21 shows the first order interaction between factor C, process batch method, and factor D, opertor reassignment policy. Fig. E.21 is plotted based on the data of means of BC interaction which are obtained from Table E.34. Fig. E.21 and the significance test of means of CD interaction in Table E.35 show and prove that the combinations involving factor D with VPB do not significantly differ in

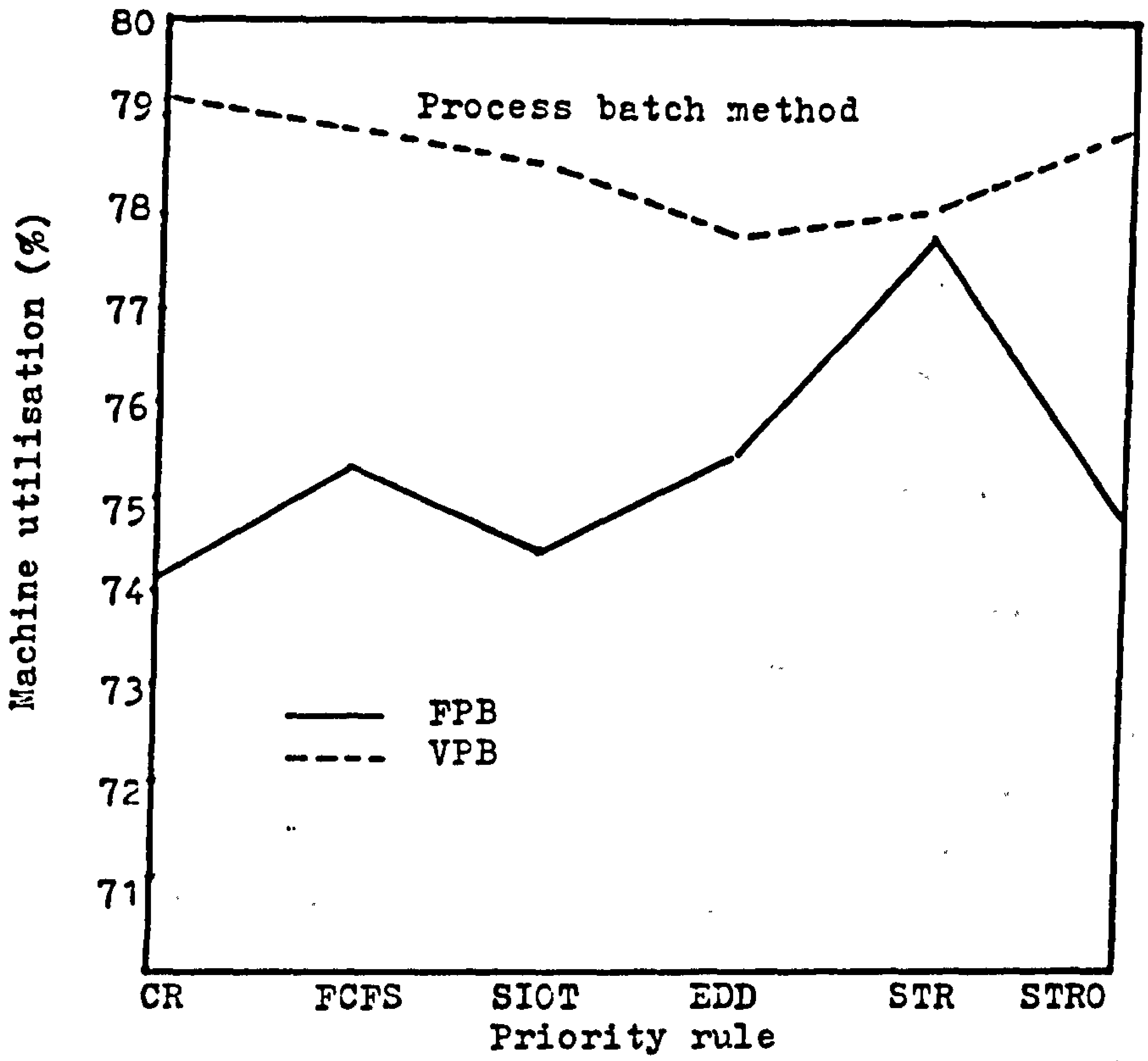


Fig.E.20. Interaction of factor B, priority rule, and factor C, process batch method in terms of machine utilisation.

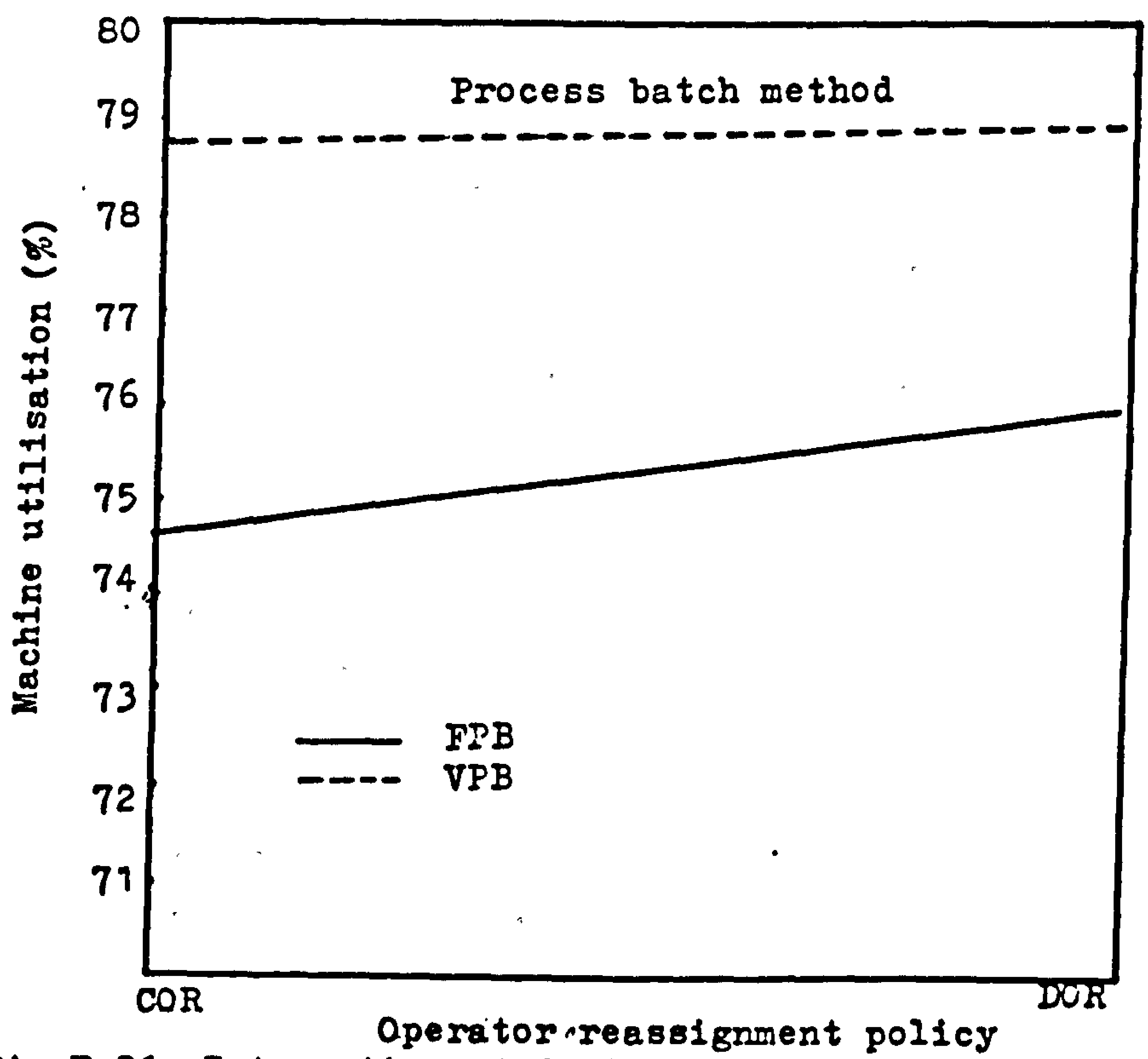


Fig.E.21. Interaction of factor C, process batch method, and factor D, operator reassignment policy in terms of machine utilisation.

respect of machine utlisation and produce a higher machine utilisation compared with the combinations involving factor D with FPB.

Referring back to Table VII.7, the ANOVA test for mean machine utilisation in this Table shows that all the first order interactions involving factor C, process batch method, are significant interactions. Therefore, the selection of a due date assignment method, or a priority rule, or an operator reassignment policy may be affected by the method by which the process batch is applied. Meanwhile, the analysis of the first order interactions in the previous sections show that the combinations which involve VPB, variable process batch, perform better than the combinations involving FPB, fixed process batch, method in terms of machine utilisation performance.

E.2.3.5 ABC Interaction

Fig. E.22 and Fig. E.23 represent the second order interaction between factor A (due date assignment method), factor B (priority rule), and factor C (process batch method) in terms of machine utilisation. Both these figures are based on plotting of the values of means of ABC interaction in Table E.36. Fig. E.22 illustrates the AB interation for each level of factor D and Fig. E.23 illustrates the BC interaction for each level of factor A. From the analysis of this interaction, there is some information that can be obtained which does not exist in the analysis of the first order interactions AB, AC, BC, and CD in terms of machine utilisation performance. This information is:

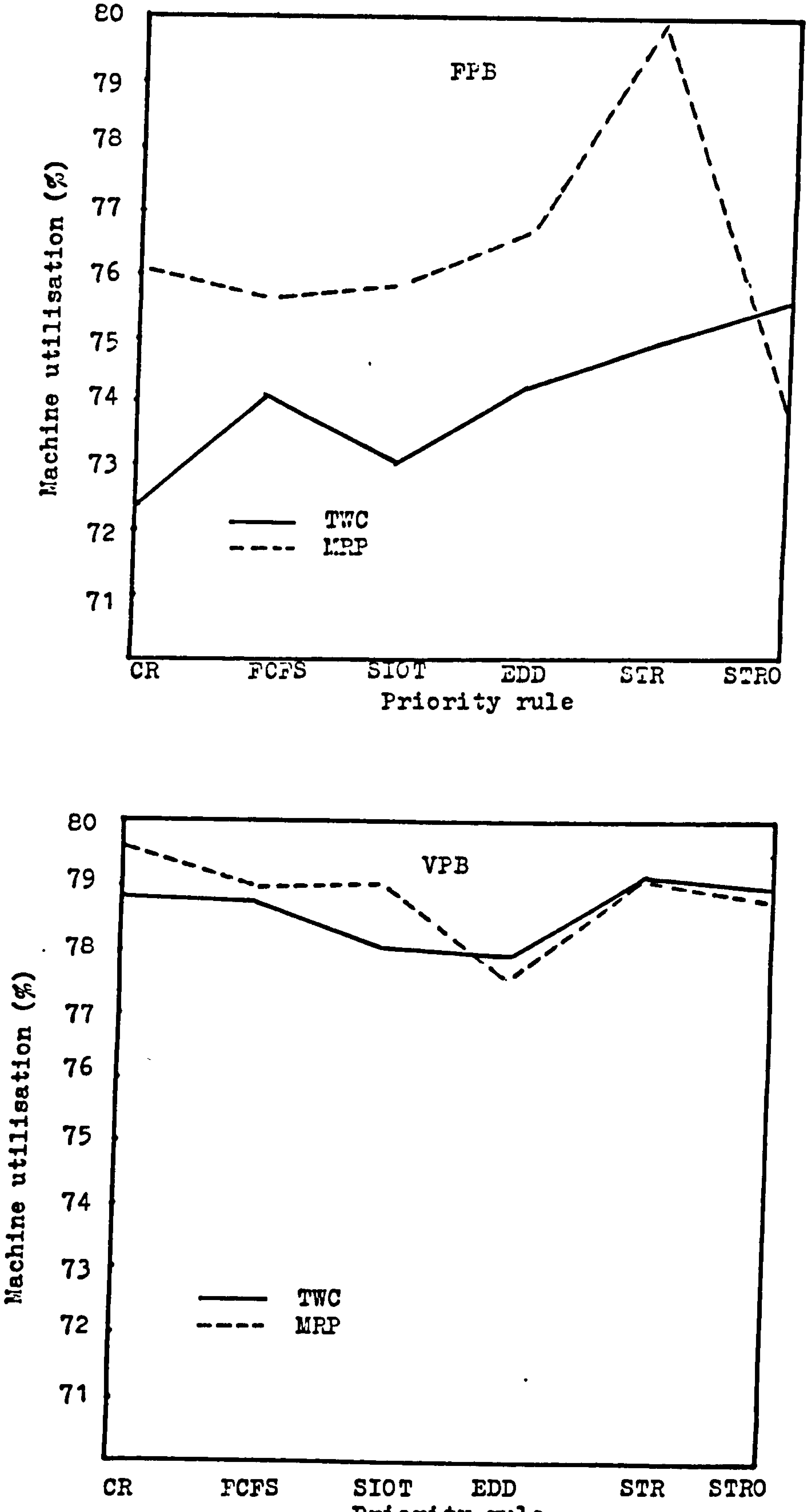
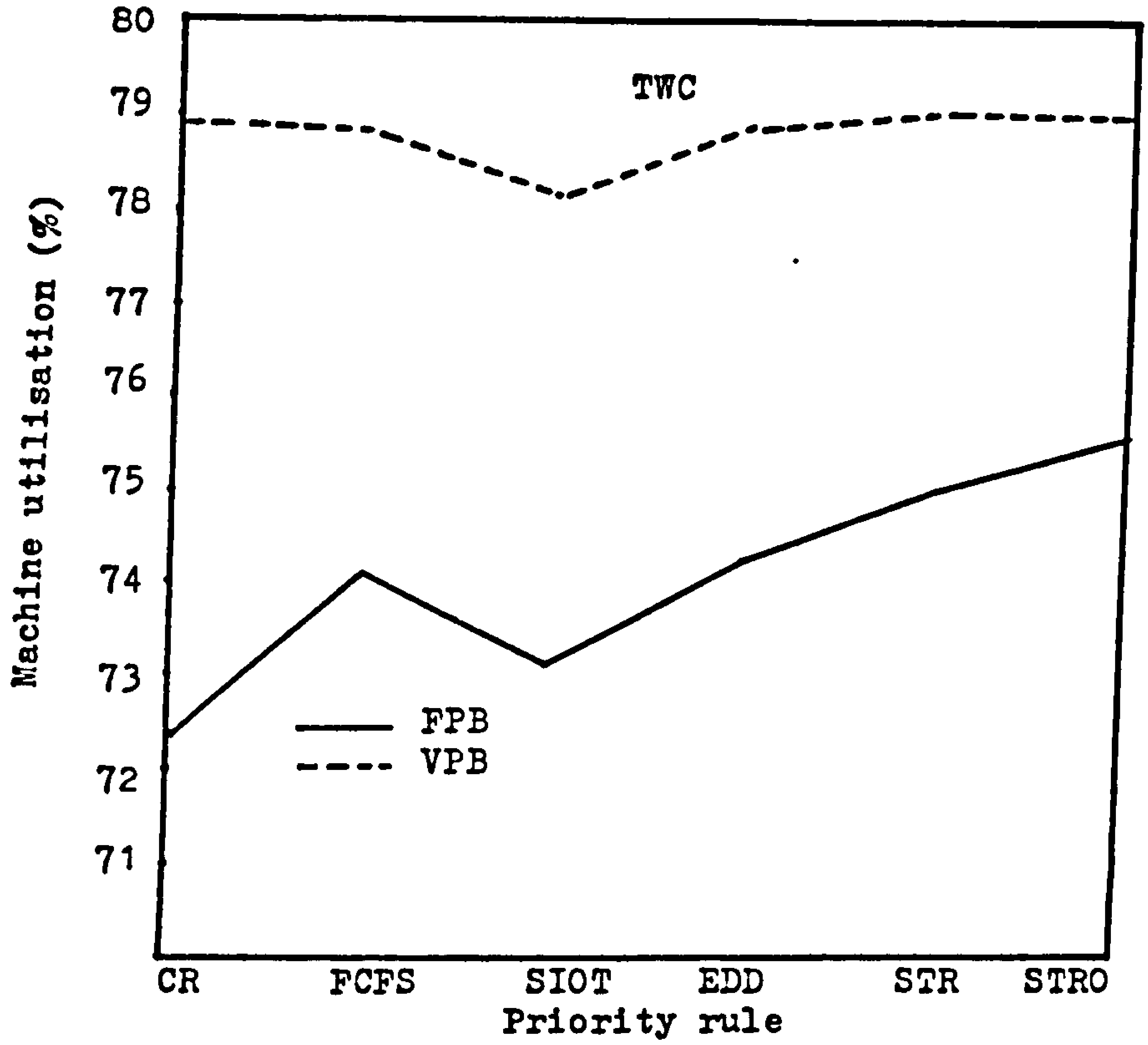


Fig.E.22. AB interaction for each level of factor C in terms of machine utilisation.



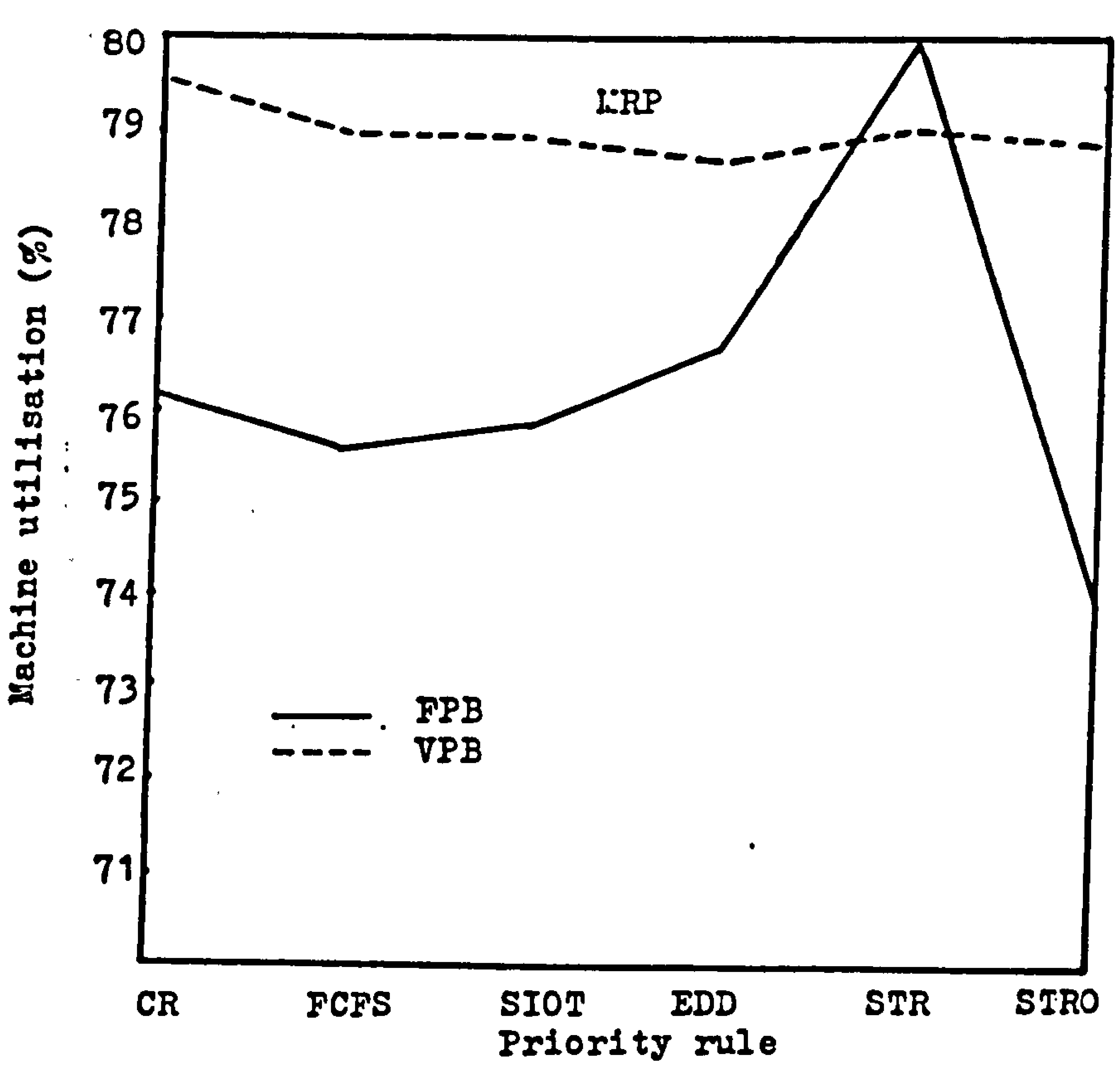


Fig.E.23 BC interaction for each level of factor A in terms of machine utilisation.

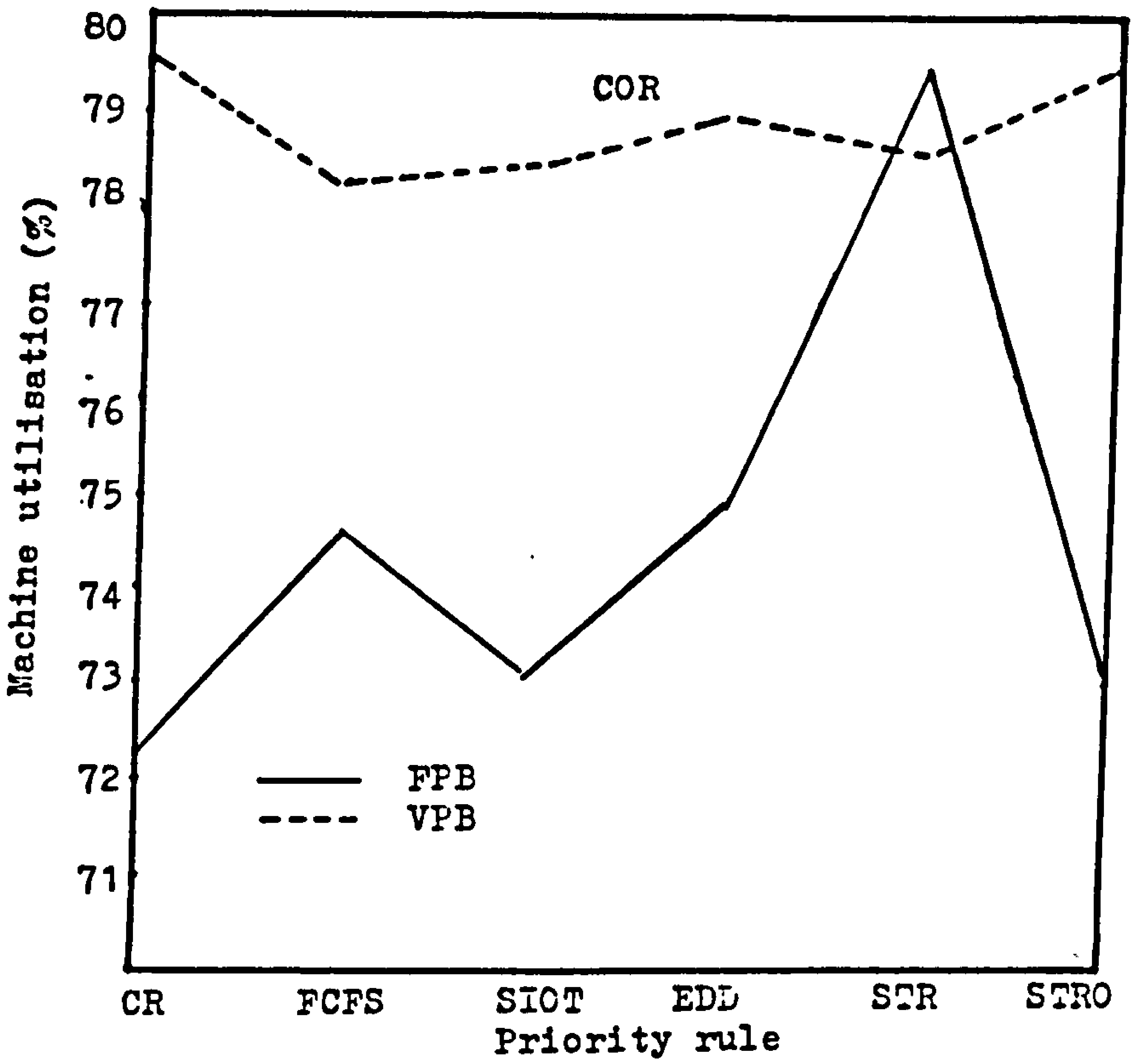
a) Every combination involving VPB, variable process batch, method produces significantly higher machine utilisation and are superior to the other combinations. Thus the VPB process batch method is superior to the FPB process batch method in terms of machine utilisation performance, regardless of the method by which the due date of finished products is assigned and by the method by which the priority rule selects the job to be processed first from the queue.

b) The combinations include TWC/CR/FPB, TWC/SIOT/FPB, MRP/STRO/FPB, and TWC/FCFS/FPB do not differ significantly and perform worst compared with the other combinations.

E.2.3.6 BCD Interaction

The second order interaction between factor B (priority rule), factor C (process batch method), and factor D (operator reassignment policy) proved to be significant according to the comparison test of means of BCD interaction in Table E.39. Fig. E.24 and Fig. E.25 based on plotting the means of BCD interaction; Table E.38 also illustrates the significancy of this interaction. Fig. E.24 illustrates the BC interaction for each level of factor D while Fig. E.25 illustrates the BD interaction for each level of factor C. Through the analysis of BCD interaction on machine utilisation performance, can be drawn some conclusions which are not evident from the first order interactions of BC and CD. These conclusions are,

a) Any combination involving VPB process batch method is significantly superior to the other



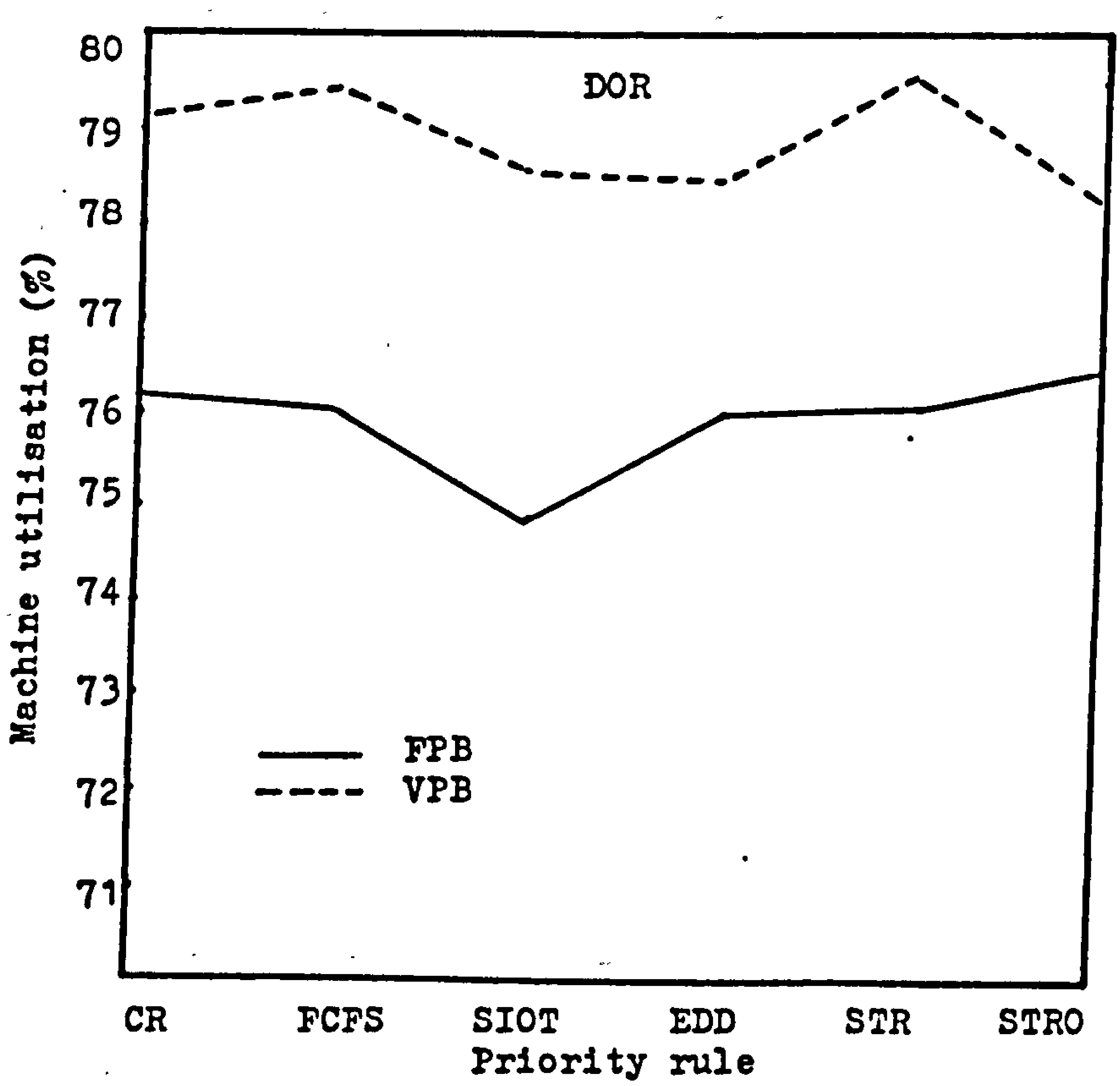


Fig.E.24. BC interaction for each level of factor D in terms of machine utilisation.

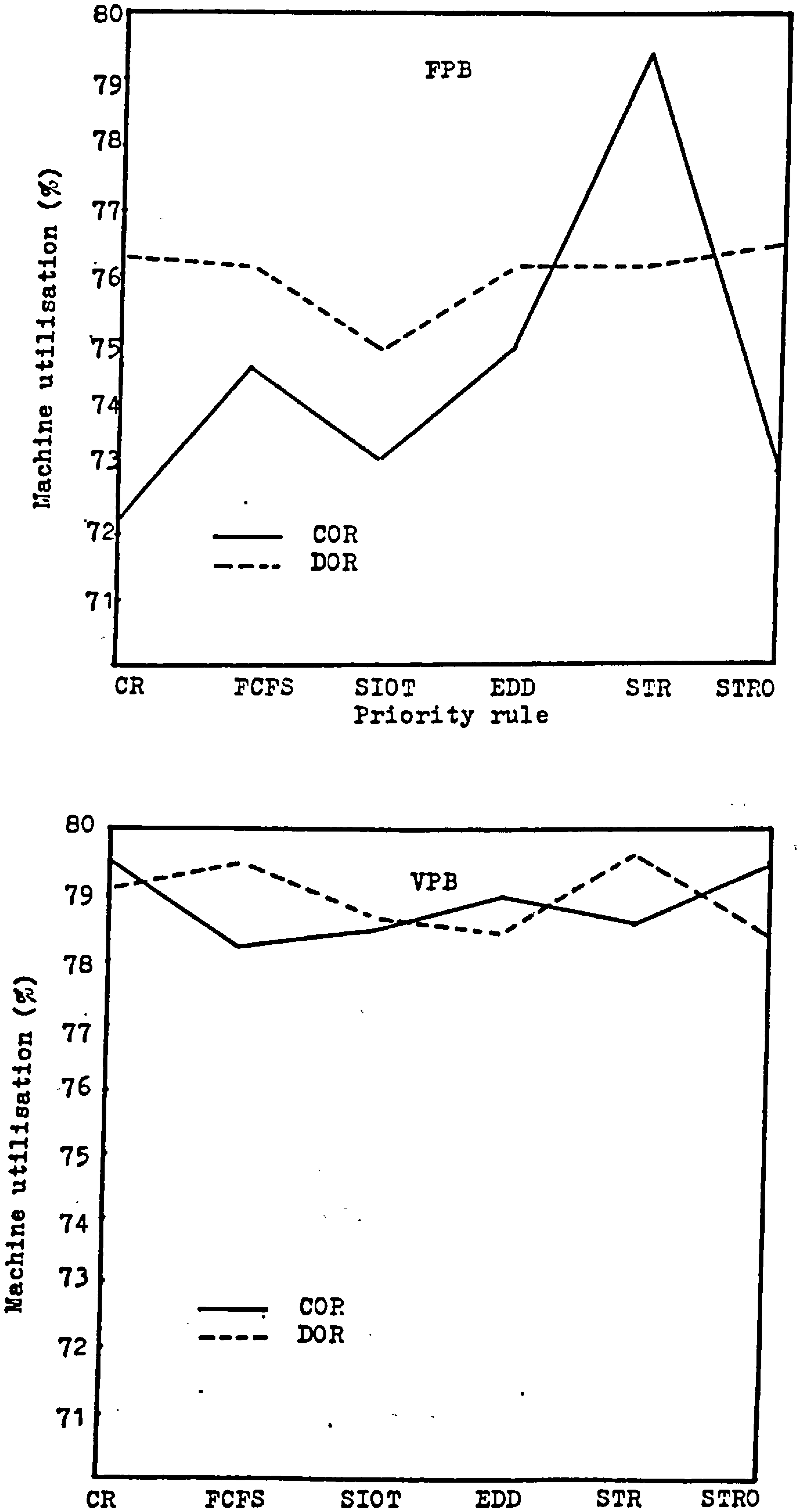


Fig.E.25. BD interaction for each level of factor C in terms of machine utilisation.

combinations and produces a higher machine utilisation. The superiority of VPB process batch method is not influenced by priority rule and operator reassignment policy.

b) The combinations including CR/FPB/DOR, STRO/FPB/DOR produce significantly lower machine utilisation compared with the other combinations and, therefore, these combinations are the worst performers.

E.2.4 Means of operator utilisation

E.2.4.1 AC interaction

A plot of the first order interaction between factor A, due date assignment method, and factor C, process batch method, is shown in Fig. E.26 (based on the data in Table E.40). Both Fig. E.26 and the significancy test in Table E.41 show that the combinations involving VPB process batch method performs significantly better than the combinations using FPB process batch method.

E.2.4.2 BC interaction

The first order interaction between factor B (priority rule), and factor C (process batch method) is illustrated in Fig. E.27 (based on the data in Table E.42). From Fig. E.27 and the significance test results in Table E.43, it can be concluded that the combinations involving VPB process batch method produce a higher operator utilisation compared with the other combinations.

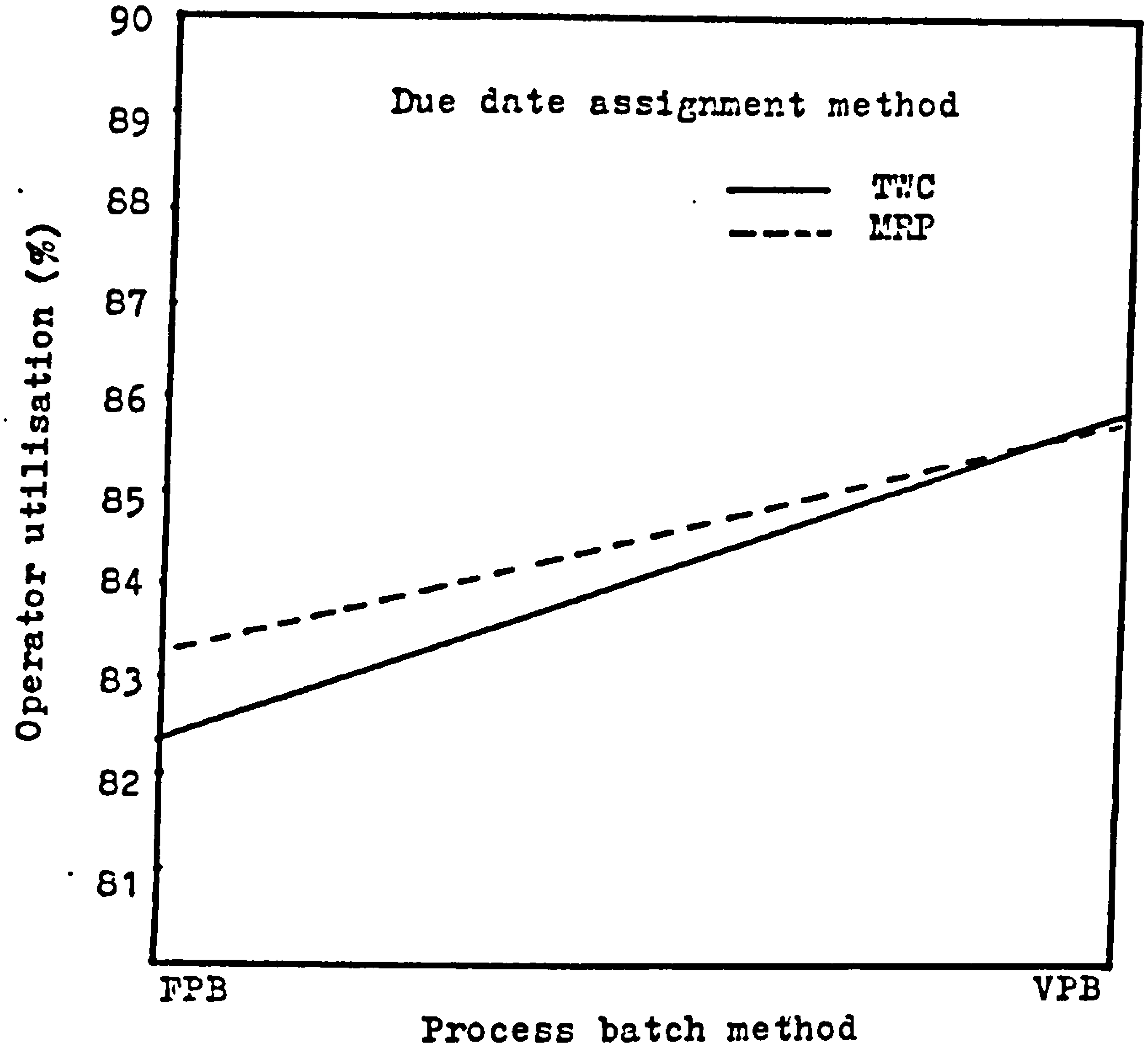


Fig.E.26 Interaction of factor A, due date assignment method, and factor C, process batch method in terms of operator utilisation.

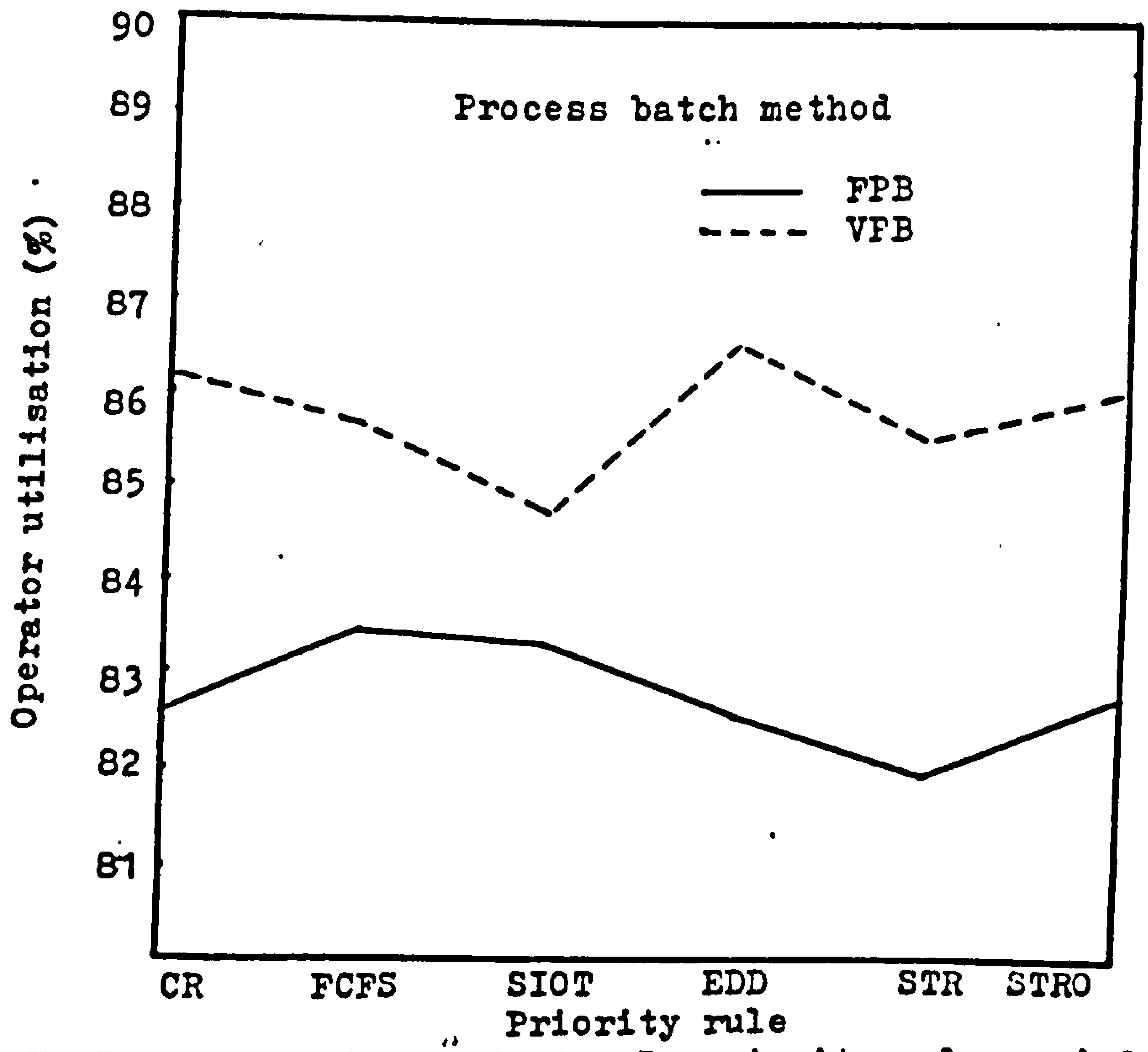


Fig.E.27. Interaction of factor B, priority rule, and factor C, process batch method in terms of operator utilisation.